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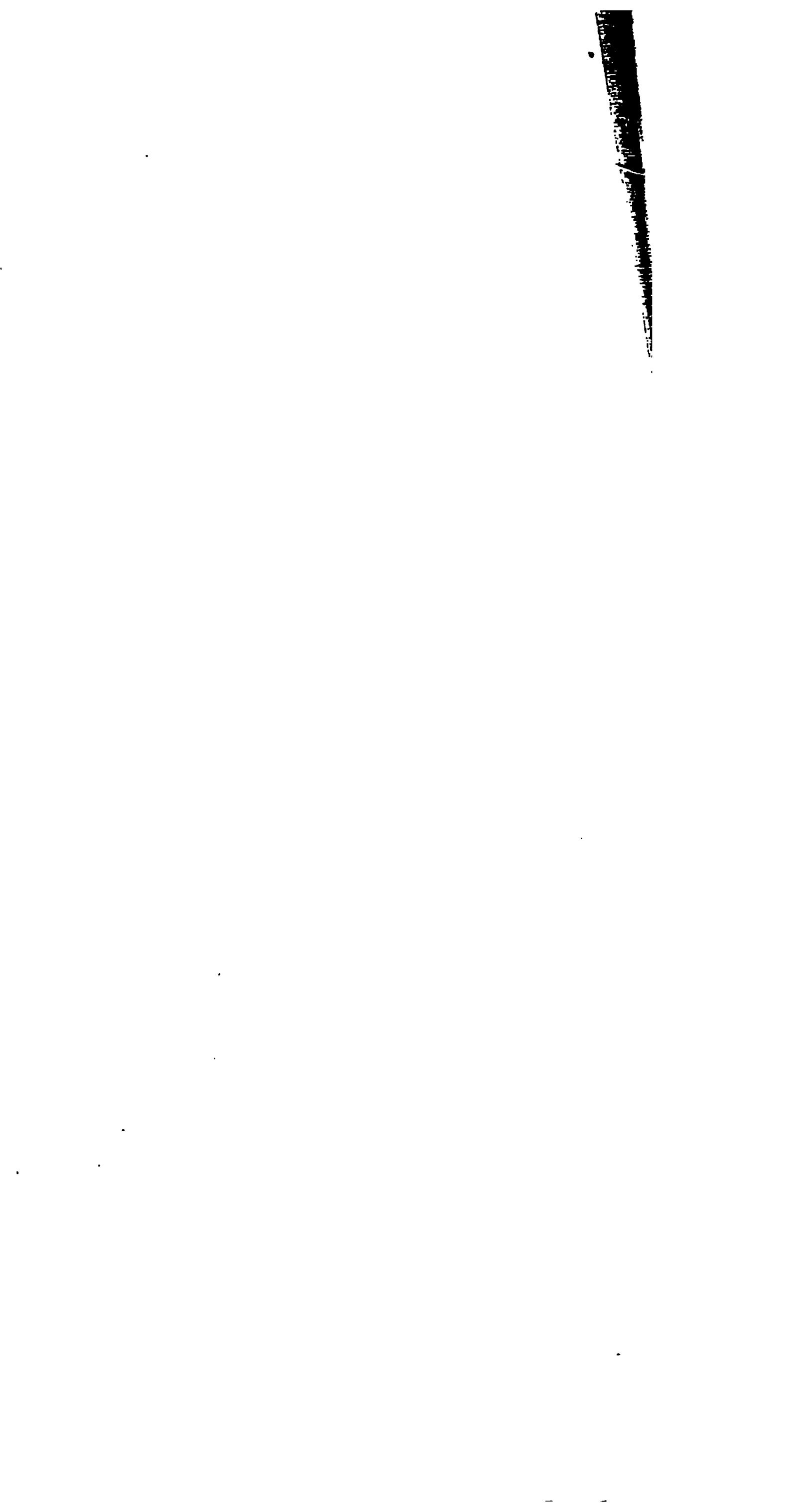
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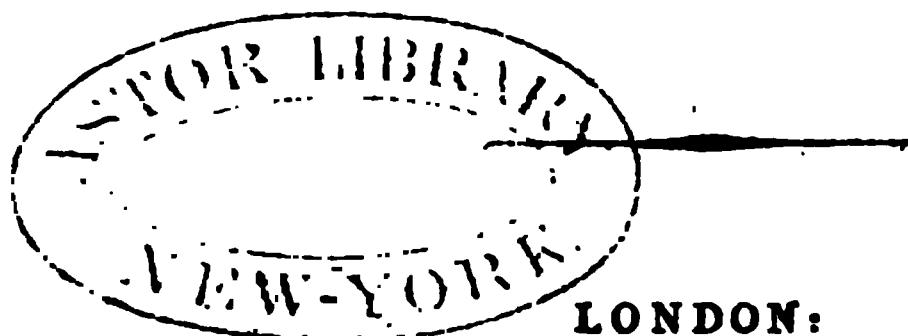


THE  
ELEMENTS  
OR  
NATURAL OR EXPERIMENTAL  
PHILOSOPHY.  
BY  
TIBERIUS CAVALLO, F.R.S. &c.

ILLUSTRATED WITH COPPER PLATES.

IN FOUR VOLUMES.

VOL. II.



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1803.

fluids are exempt from those laws, as far however as their nature admits of their being placed in circumstances similar to those of the solids; but because the mechanic of fluids contains certain other laws which are not applicable to solids; hence the particular examination of the equilibrium and of the motion of the fluids, was reserved for the present part.

We are now going to treat of the peculiar properties of bodies, viz. of such as render one piece of matter, or set of bodies, different from another piece of matter, or other set of bodies; and of such properties there are some which belong to a great number of bodies, though not to all; others which belong to a few; and, lastly, there are other properties, which belong to single bodies only. Thus water, oil, spirit of wine, and air, are all *fluid* substances, so that by that fluidity they are distinguished from stones, metals, wood, bones, &c. which are all *solid* substances. But, though water, oil, spirit of wine, and air, be all called fluids; yet the first three are distinguished from the last, by this, viz. that they are not compressible into a narrower space by the application of any mechanical force, at least not in any remarkable degree; whereas air may be easily compressed into a narrower space. Hence water, oil, and spirit of wine, are said to be non-elastic fluids; but air is said to be an elastic fluid. Farther, though water, oil, and spirit of wine, be all three non-elastic fluids,

Fluids, yet the first may be distinguished from the other two, by its not being capable of inflammation; whereas oil and spirit of wine may be easily inflamed and burned away. Yet though these two agree in the property of being inflammable, they may however be easily distinguished from each other by means of other peculiar properties; common oil, for instance, is much less fluid than spirits; it also feels clammy to the fingers, which spirit of wine does not; it is less inflammable, and less evaporable than spirits, &c.

This short sketch of the nature and variety of the natural properties of bodies, will sufficiently manifest the multiplicity of particulars which must be noticed in the present part of these elements; and will, at the same time, point out the necessity of preserving as much order and perspicuity, as the intricate nature of the subject can admit of.

With this view we shall begin by making a slight, but general, survey of the Universe, or rather, of the bounds of human knowledge relative to the number and variety of natural bodies; whence the reader may form some idea of the extent, variety, and importance, of the subject. But previous to this, it will be proper to make the following observation.

It is a rule in elementary compositions, to explain those articles first, which may elucidate what follows;—to take nothing for truth, unless it has been previously proved; and not to mention any



4      *Of the peculiar Properties of Bodies.*

thing which has not been already described. But the strict adherence to this rule is impracticable in natural philosophy, wherein hardly any thing can be mentioned, which does not owe its existence to the previous existence of several other things, which cannot have been all previously described. Thus, in speaking of the fusibility of metals, we must naturally mention the thermometer; and in describing the thermometer, we must naturally suppose the previous knowledge of the fusibility of glass, and of the nature of quicksilver, which is the metallic substance mostly used for the construction of that very useful instrument. The reader, however, need not be under any apprehension of being misled or confused; for whenever any article is mentioned without its having been previously explained, he may be assured, in the first place, that the particular description of that article is not necessarily required in that place; and secondly, that the proper description of that article will be found in some other more appropriate part of the work.

## CHAPTER I.

CONTAINING AN ENUMERATION OF THE VARIOUS  
KNOWN BODIES OF THE UNIVERSE, UNDER GE-  
NERAL AND COMPREHENSIVE APPELLATIONS.

THE most distant objects, that are at all per-  
ceivable by any of our senses, are the lumi-  
nous coelestial bodies, amongst which the Sun is  
the grandest and the most admired of the creation.  
Its splendor, its heat, and its beneficial influence,  
have always excited the particular attention of the  
human species, and have obtained the adoration of  
all those nations, which have not been blessed with  
the light of Revelation. Next to it is the Moon,  
whose apparent size nearly equals that of the Sun ;  
but its splendor is vastly inferior. The other nu-  
merous bright objects of the heavens differ from  
each other in size and lustre ; but in those respects  
they all appear greatly inferior even to the Moon.  
Amongst them there are six, which are seen to  
move with apparent irregularity, but under certain  
determinate laws, through certain parts of the  
heavens ; whilst the others appear to remain at the  
same unalterable distance from each other.—The  
former are called *Planets*, and their particular names  
are, *Mercury*, *Venus*, *Mars*, *Jupiter*, *Saturn*, and the

*Georgian Planet*: but it will be shewn hereafter, that the Earth we inhabit is likewise a planet, which renders the planets seven in number. The latter are called *Stars*, the principal of which have likewise obtained particular names; but they are too numerous to be inserted in this place.

Besides the Stars properly so called, and the planets, which are always visible to the inhabitants of the Earth, several other luminous objects are at times seen in the heavens, which appear for a considerable time, move in a manner apparently more irregular than the planets, then disappear, and perhaps make their appearance again after a long period of years. These are called *Comets*.

By means of the telescope it has been discovered, that four small luminous objects revolve at certain distances round the planet Jupiter; seven such bodies revolve round the planet Saturn, and six revolve round the Georgian Planet. Those small revolving bodies are called *Satellites*, or *Moons*; for in fact the Moon itself will be shewn to be a Satellite, which moves round the Earth, in the same manner as the abovementioned satellites revolve round their respective planets in stated periods.

The science which enumerates those coelestial objects, which describes their peculiar appearances, which examines and calculates their movements, and which renders that knowledge useful to the human species, is called *Astronomy*, the elements of which

which will be explained in the fourth part of this work.

The celestial bodies which have been just mentioned, and such as fall under the cognizance of Astronomy, do all move under certain laws, which, even with respect to the Comets, have been in a great measure investigated and ascertained. But there are several other objects, either luminous or opaque, which appear in the sky at uncertain times, and which do not follow any known regularity of motion; so that they very seldom appear twice in the same place, and of precisely the same shape. These are, for very strong reasons, supposed to be much nearer to us than the Moon, which is the nearest to us of all the celestial bodies that have a known regularity of motion. They are collectively called *Meteors*, whence the particular examination of their origin, of their appearances, and of their influence, or of their effects, forms the subject of *Meteorology*, which is a very considerable branch of Natural Philosophy.

The principal objects of Meteorology are, 1. Those luminous appearances, which are commonly called *Falling Stars*, or *Shooting Stars*, the largest of which are more particularly called *Meteors*. 2. The quick moving light, which is seen at times in the sky, especially about the North and South Poles, and which has hence been denominated the *Aurora Borealis*, and *Aurora Australis*, or *Northern* and *Southern Lights*. 3. The *Rain-bow*. 4. *Halo's*, or *Corona's*.

## Of the known Bodies

*Corona's*, viz. those steady white circles which are sometimes seen about the Sun and the Moon. 5. *Parhelia*, or *Mock Suns*, and *Paraselenæ*, or *Mock-Moon*. 6. The *Zodiacal Light*. 7. Other luminous appearances more irregular and less remarkable than the preceding, which have obtained, from their more usual shapes, situations, &c. the various names of *Draco Volans*, viz. *Flying Dragon*, or *Flying Kite*; *Luminous Arches*; *Luminous Clouds*; *Ignis Fatuus*, vulgarly called *Will with a wisp*, or *Jack in a lanthorn*, or *Jack-a-lanthorn*; the *Fata Morgana*, &c. 8. *Thunder* and *Lightning*. 9. *Vapours*, *Fogs*, *Mists*, and *Clouds*. 10. *Rain*, *Hail*, and *Snow*. 11. *Water Spouts*. 12. *Winds*, under the various names of *Trade Winds*, *Monsoons*, *Gales*, *Whirlwinds*, &c. 13. *Storms*, and *Hurricanes*.\*

Some authors have reckoned the natural formation of ice, or the frost, as also earthquakes, volcanos, &c. amongst the meteors; but it will be much better to confine the word meteor to its original signification, viz. to something that takes place in the sky above us, but nearer to us than the Moon.—The nature, origin, and effects of the above enumerated meteorological objects, as also of volcanos, of earthquakes, &c. will be described in different parts of these elements.

\* Those objects of meteorology have been usually said to be of three kinds, viz. *fiery*, *watery*, and *airy*, *meteors*. But this distinction is both useless and improper.

We must lastly enumerate the various bodies which form the Earth, or the planet we inhabit.

A variety of observations, experiments, measurements, and incontrovertible arguments, the principal of which will be mentioned hereafter, have proved that this Earth is not a perfect sphere; but that it is a little flattened on two opposite parts, which give it the figure of an *oblate spheroid*; the longest diameter of which has been reckoned equal to 41960862 English feet, or 7947 English miles; the shortest diameter has been reckoned equal to 41726516 English feet, or 7902,1 English miles; the difference of the two diameters being 234345,6 feet, or 44,4 miles.\*

The

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\* See De la Lande's Astronomy, vol. III. *De la Figure de la Terre et de son aplatissement*; where, viz. in §. 2690, and 2693, the two diameters are shewn to be equal to 6562024, and 6525376 French toises, from which the above-mentioned lengths have been derived; a French toise being equal to 6,3945 English feet.

Sir Isaac Newton, supposing the earth to be of uniform density, assigned for the difference between the equatorial and polar diameters  $\frac{1}{335}$  part of the former. Boscovich, taking a mean from all the measures of degrees, found the difference of the two diameters equal to  $\frac{1}{241}$ . From other measurements made in various parts and calculated by different able mathematicians, this difference has been reckoned equal to  $\frac{1}{311}$  or  $\frac{1}{300}$  by de La Lande; to  $\frac{1}{321}$  by de La Place; to  $\frac{1}{367}$  by Sejour.—These latter results agree pretty well with the observations of the length of the pendulum made

The surface of the Earth consists of land and water variously intermixed. The land is usually divided into, 1. *Continents*, or very large tracts comprehending several countries, states, &c. 2. *Islands*, or spots of dry land, having water all round. 3. *Peninsulas*, or spots of dry land surrounded by water, excepting a small neck or communication with some other land. 4. *Isthmuses*, or necks of land, which join the peninsulas to other land. 5. *Promontories*, or high lands extending themselves into the sea, the extremities of which are called *Capes* or *Head-lands*. And lastly, *Mountains*, which are parts of the land considerably elevated above the adjacent country; the smallest of which are called *Hills*.

The watery part of the surface is usually divided into, 1. *Oceans*, or vast collections of salt water, viz. the largest divisions of the watery part of the surface. 2. *Seas*, or parts of oceans, close to, or between some countries. 3. *Gulfs* or *Bays*, which are seas having land all round, except on one side, by which

made in different latitudes; so that upon the whole  $\frac{3}{4}$  or a fraction not much differing from this, seems to be the nearest to the truth. The causes of disagreement between the results of different measurements, probably are the imperfection of instruments, the partial attraction of mountains, and the unequal density of the materials within, and at no great distance from the surface of the earth. See Professor Playfair's paper on the fig. of the Earth in the Trans. of the R. S. of Edinburgh, vol. V. P. I.

they communicate with other seas or oceans. 4. *Straits*, or *Friths*, being narrow branches of the sea between two contiguous lands, or narrow passages from one sea to another. 5. *Lakes*, or collections of water in some inland place. And 6. *Rivers*, or *Streams of Water*.

The particular description of those parts, as also of the political division of the Earth, form the subjects of *Geography* and *Hydrography*.

There are several hollows or natural pits in the Earth; but they either do not descend, or could not be examined, to any great depth. Deep pits have also been made by human art; but the deepest of them do not exceed 2400 feet, or less than half a mile; so that the industry of man has not been able to penetrate so far below the surface of the Earth as half a mile, which is a very short distance indeed, when compared with the abovementioned lengths of the diameters. So that whatever lies below that depth is to us utterly unknown.

The materials which have been extracted from those excavations are not in general of a nature different from those, which in some particular places have been found immediately upon the surface of the earth.

Upon that surface a vast variety of objects is to be observed; but those various objects, together with those that are dug, have been usually arranged under three grand divisions, which are naturally suggested by their more striking properties, and which

which have been emphatically called the *three Kingdoms of Nature*; viz. the *Animal Kingdom*, which comprehends all those self-moving, organized bodies, of which the human being forms one species. The *Vegetable Kingdom*, which comprehends all those organized bodies called *plants*, which grow by an enlargement of parts, have a certain period of life or of existence; but are attached to a particular part of the soil, from which they derive the greatest part of their nourishment. And lastly, the *Mineral Kingdom*, which comprehends all the other bodies of the Earth; for all the others are sometimes found within the Earth, whereas living animals and living plants are not to be found buried at any considerable depth below the surface of the Earth.

Every one of those three grand divisions is subdivided into a variety of subordinate subjects. Thus the particular enumeration and classification of all living creatures, or organized bodies, which give marks of sensation, which continue their kinds according to invariable laws, and which are found in the state of embryo, infancy, maturity, old age, or death, forms the subject of *Zoology*.—*Anatomy* examines and describes the internal and external parts of the animal body. *Medicine*, or the *Medical art*, endeavours to preserve or to restore the health of animals, and is itself subdivided into other branches, &c.

Thus

Thus also with respect to the vegetable kingdom, the enumeration and regular arrangement of all the plants forms the science of *Botany*. The art of cultivating them is called *Agriculture, Husbandry, &c.*

In like manner with respect to minerals, the enumeration and arrangement of all their species, together with the description of such of their properties as are necessary to discriminate them from each other, forms the subject of *Mineralogy*. The consideration of their original formation, and of their present natural disposition in the body of the Earth, is denominated *Geology*. The particular knowledge and management of one sort of minerals, viz. of metallic substances, is called *Metallurgy*; and so forth.

When the knowledge of those various subjects was not very extensive, all the known particulars could be easily arranged under the general title of Natural Philosophy; but the progress of civilization, and the unremitting attention which has been bestowed, particularly within the two last centuries, on scientific subjects, have increased the number of useful discoveries to such a degree, as to render the capacity of one man inadequate to the comprehension of the whole stock of knowledge, and much less able to treat of all the above-mentioned subjects in a full and complete manner. Therefore, under the title of Elements of Natural Philosophy, we mean to explain the principles,

principles, or the foundation of all those various branches of knowledge, which depend upon the properties of natural bodies ; whence the student may obtain a competent knowledge of the whole, and particularly of the admirable connexion which exists between them all, upon which, as upon a steady foundation, he may extend his knowledge of any particular branch, which his inclination or his profession may lead him to adopt.

Almost all the bodies which come under the cognizance of our senses, viz. all the animals, all the vegetables, and almost all the minerals, are compound bodies ; viz. they evidently consist of substances differing in weight, colour, and other properties, which may be separated more or less easily from each other ; but when separated to a certain degree, the human art is not able to decompose them any farther. Now those substances or components of animal, vegetable, and mineral bodies, which appear of a uniform nature, and which, at present, cannot be divided into more simple substances, must be reckoned elementary or primitive, until a mode of decomposing them be discovered. Thus, for instance, water was formerly reckoned an elementary substance ; but it has been of late years discovered, that it consists of (for it may be resolved into,) other substances, which possess properties very different from each other. Hence, at present, water is no longer looked upon as an elementary substance. It, therefore, naturally

turally appears that the number of elements must have been always fluctuating, and that it is likely to continue so for ages to come, since the ingenuity of man continually discovers new substances, and at the same time finds means of reducing into simple substances several such bodies as had before passed for simple, primitive, or elementary.

The scientific persons of the present time acknowledge the substances of the following list, as the elements or components of all animals, vegetables, and minerals; yet it will presently be shewn that some of those elements are merely hypothetical, and that they have been admitted as such, by reasoning from analogy upon other facts.

### ELEMENTARY SUBSTANCES:

Light	Radical succinic
Calorific, or caloric	Radical acetic
The Electric fluid	Radical tartaric
The Magnetic fluid	Radical pyro-tartaric
Oxygen	Radical oxalic
Hydrogen	Radical gallic
Azote	Radical citric
Carbon	Radical malic
Sulphur	Radical benzoic
Phosphorus	Radical pyro-lignic
Radical muriatic	Radical pyro-mucic
Radical boracic	Radical camphoric
Radical fluoric	Radical lactic
	Radical

Radical sach-lactic	Zinc
Radical formic	Iron
Radical Prussic	Tin
Radical sebacic	Lead
Radical bombic	Copper
Radical laccic	Mercury
Radical suberic	Silver
Radical zoonic	Platina
Arsenic	Gold
Mollybdenite	Silica
Tungsten	Argill
Chrome	Baryt
Titanite	Strontian
Sylvanite	Lime
Uranite	Magnesia
Manganese	Jargonia, or Zirgonia
Nickel	Pot-ash
Cobalt	Soda, and
Bismuth	Ammoniac
Antimony	

The first four of those elements may with propriety be called hypothetical. These are *Light*, or that fluid which renders objects perceptible by our eyes; *Caloric*, viz. the fluid which is supposed to produce the phenomena of heat, or to affect us with the sensation of heat; the *Electric Fluid*, which is supposed to produce the phenomena called *electrical*, and the *Magnetic Fluid*, to which the properties of the magnet are attributed; for, in

in fact, the phenomena which fall under each of those four denominations, are only supposed to be the effects of a single fluid; respecting the nature of which, however, various opinions are entertained.

We shall treat at large of those four very remarkable natural agents in the third part of this work; yet some of their properties must unavoidably be mentioned in treating of the properties of all the other elementary substances, in the present part.

With respect to the latter, it may likewise be observed, that some of them are only supposed to exist from analogy. Thus it is known that the sulphuric acid consists of sulphur and oxygen; for it may be formed by combining those two substances together, and it may be reduced into those substances. It is likewise known, and for the like reason, that the carbonic acid consists of carbon and oxygen; but the components of the muriatic acid are not known with certainty; yet from the analogy of other acids, the muriatic acid is supposed to consist of oxygen joined to something else, which something else has been called the base of that acid, or the *muriatic radical*. The like observation may be applied to some other radicals.

The knowledge of the existence of the above-mentioned elementary substances, excepting the first four, has been acquired by the actual decomposition of animal, vegetable, and mineral bodies, such as are usually found; and likewise by the

actual re-composition or formation of some bodies in a great measure similar to the natural; from a combination of some of the elementary substances. The art of decomposing natural bodies is called *Analysis*;—the art of forming compounds is called *Synthesis*; and both the art of analysing, and the synthetical art, together with the knowledge of the principal facts which have been ascertained by those means, form the science of *Chemistry*.

Having thus far given a general idea of all the bodies, which either are known to exist, or are, for very strong reasons, supposed to exist; I shall now subjoin a short but comprehensive view of their properties; and shall, at the same time, point out the order in which the particular description of those properties will be arranged in the following chapters.

It has been shewn in the first part of this work, that matter in general is possessed of *extension*, *divisibility*, *impenetrability*, *mobility*, *vis inertiae*, and *gravitation*.—Upon the mobility and the *vis inertiae* of bodies, the extensive doctrine of motion or the mechanical laws, have been established; but that doctrine cannot be sufficiently elucidated, unless it be particularly adapted to each of the three principal states of bodies, viz. to solids, to non-elastic fluids, and to elastic fluids; therefore, having already explained the mechanical laws with respect to solids, it will be necessary, in the next place,

plate, to treat of the mechanical properties of non-elastic fluids, under the title of *Hydrostatics*; then of the mechanical properties of elastic fluids, under the title of *Pneumatics*; and lastly, of the other peculiar properties, besides the mechanical, which belong to each of them, viz. to solid and fluid, to simple and to compound, bodies, under the title of *Chemistry*.

The properties of bodies may be said to be either of a *passive* or of an *active* nature. The former are *extension*, *figure*, *divisibility*, *impenetrability*, *mobility*, *vis inertiae*, *density* and *rarity*, *hardness*, *softness*, *fluidity*, *rigidity*, *flexibility*, *elasticity*, *opacity*, and *transparency*; which have been sufficiently defined in the preceding pages, and will be farther explained in the following; or their meaning is commonly too well known to require any particular definition. The latter, or those of an *active* nature, are *attraction* and *repulsion*.

Besides what relates to light, heat, electricity, and magnetism, there are four sorts of attraction, viz. 1st. The attraction which every known body has towards all the rest, and which is called *gravitation*; 2dly. The attraction which homogeneous parts of matter have towards each other, or by which they adhere to each other, and which is called the *attraction of aggregation*; and such is the power by which two small drops of quicksilver, when placed contiguous to each other, rush, as it were, into each other, and form a single drop;

20      *Of the known Bodies of the Universe.*

3dly. The *attraction of cohesion*, or that power by which the heterogeneous particles of bodies adhere to each other without any change of their natural properties ; such as the adhesion of water to glass, of oil to iron, &c. 4thly. The *attraction of composition* or of *affinity*, which is the tendency that parts of heterogeneous bodies have towards each other, by which they combine, and form a body, differing more or less from any of its components.\*

Repulsion takes place either between the homogeneous, or between the heterogeneous, parts of bodies ; but the existence of the former is with great reason much doubted.

It is remarkable that of all those properties we only know their existence, and some of the laws under which they act ; but we are otherwise utterly ignorant of their nature and dependence.

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\* The investigation and the knowledge of this last sort of attraction, or affinity, is the most useful and extensive, it being the foundation of chemistry and of various arts. Its investigation is likewise very intricate, for it is different between any two bodies from what it is between any two others, and it fluctuates according to a vast variety of circumstances. Thus, for instance, a certain body A has a greater tendency to mix with another body B in a particular temperature, than in any another. The same body A has a greater affinity to another body B, than to a third body C, and it may have no affinity at all, or even a repulsion, towards a fourth body D. Yet when D and C are mixed so as to form one compound body, then A may have an affinity to that compound.

## CHAPTER II.

### OF HYDROSTATICS.

**HYDROSTATICS** is the science which treats of the pressure and equilibrium of non-elastic fluids\*; *Hydrodynamics* is the science which treats of fluids in motion; and *Hydraulics* treats of the construction of certain machines or engines in which fluids are principally concerned. But we shall now treat of what relates to non-elastic fluids, without taking any farther notice of those nominal distinctions. †

A

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\* This science began to be cultivated by the great Archimedes.

† Water, oil, spirit of wine, and other such fluids, are said to be *non-elastic*, or *non-compressible*, not because they are absolutely so; but because their compressibility is so very small as to make no sensible difference in our calculations relative to the pressures, movements, and other properties of those fluids.

The ingenious Mr. Canton, in the year 1761, discovered the compressibility of water, of oil, &c. in the following manner. He took a glass tube having a ball at one end, much in the shape of a thermometer glass; filled the ball and part of the tube with water, which had been deprived of air as

A perfect fluid is that whose parts may be moved from each other by the least force. But such a fluid is not to be found; for independent of its gravity, or weight, or tendency towards the centre of the earth, every non-elastic fluid is possessed of the

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much as it was possible; then placed it under the receiver of an air-pump, and on exhausting the receiver, (viz. on removing the pressure of the atmosphere from over the water and the glass in which it was contained) the water rose a little way into the tube, viz. expanded itself. And, on the contrary, when he placed the apparatus under the receiver of a condensing engine, and by condensing the air in the receiver, increased the pressure upon the water, a diminution of bulk took place, for the water descended a little way into the tube. "In this manner," he says, "I have found by repeated trials, when the heat of the air has been about  $50^{\circ}$ , and the mercury at a mean height in the barometer, that the water will expand and rise in the tube by removing the weight of the atmosphere, one part in 21740; and will be as much compressed under the weight of an additional atmosphere. Therefore the compression of water by twice the weight of the atmosphere is one part in 10870."

"Water has the remarkable property of being more compressible in winter than in summer, which is contrary to what I have observed both in spirit of wine and oil of olives."

Mr. Canton likewise subjected other fluids to the like experiments, and found them susceptible of compression and expansion in the following proportions:

Compression

the attraction of aggregation (viz. of the mutual attraction between its parts) in a particular degree; of the attraction of cohesion, which is likewise in a particular degree, towards other bodies, and of the attraction of affinity. Besides which a sort of obstruction or want of perfect freedom may be observed more or less in all fluids. For instance, a small drop of water placed upon a dry and clean glass plate, does not assume an horizontal surface, but remains nearly of a globular form; its attraction of aggregation, which draws every part of it towards its centre, being greater than its gravity; and its attraction of cohesion towards the glass being just sufficient to let the drop adhere to the glass, when the latter is turned upside down. But if the drop be spread over the surface of the glass, then the film of water will adhere to the glass with greater force, nor will it

Compression	{	of spirit of wine 66	}	millionth parts.
		of oil of olives - 48		
		of rain water -- 46		
		of sea water -- 40		
		of mercury - - - 3		

Mr. Canton was of opinion that this small degree of compressibility is not owing to the compression of any air which might be lodged within those fluids; for, having caused a quantity of water to imbibe more air than it contained in a preceding trial, he found that its compressibility was not thereby increased.—Canton's Papers in the Phil. Trans. vol. 52d and 54th.

recover its former globular form ; because by the spreading, its particles have been brought nearer to the glass, and the whole drop has been brought into contact with a much greater surface of the glass ; by which means the attraction of cohesion, or attraction towards the glass, has been rendered much greater than the mutual attraction between the particles of water (for either of those attractions is increased or diminished by bringing the parts nearer to, or by removing them farther from each other), and it has likewise been rendered much greater than the attraction of gravitation.

If the same experiment be tried with a small drop of quicksilver, instead of water, this also will assume a globular form, in consequence of its attraction of aggregation ; and it will adhere to the glass, if the latter be turned upside down, on account of its attraction of cohesion. But it will be found impossible to spread it over the glass, because its attraction of aggregation is much greater than its attraction of cohesion towards the glass.

When the quantity of fluid is considerable, as a cup nearly full of water, then the attraction of cohesion is much smaller than its gravitation, and the greatest part of the fluid lies too far from the sides of the cup, to be sensibly affected by its attraction. Hence the surface of the water, in consequence of its gravitation, (as will presently be shewn) will be horizontal, excepting that part of it which lies near the sides of the cup, which will be attracted, and,

ascending a certain way, will drag part of the contiguous water in consequence of its attraction of aggregation, so as to form a concave surface. On the other hand, by a little care, more water may be put in the cup than its absolute capacity, or, speaking more justly, the water may be made to project above the edge of the cup, and then near the edge it will assume a surface visibly convex; it being prevented from falling over to a certain degree, by both the attraction of aggregation, and the attraction towards the sides of the cup.

Thus much may be sufficient to shew that both the quiescent state of fluids, and their movements, are influenced by a variety of powers: but as gravitation is the principal acting power, when the quantity of fluid is not very small, we shall therefore proceed to state and to explain the laws of hydrostatics, upon the supposition that fluids are actuated only by the power of gravity; for we shall afterwards endeavour to point out the principal deviations from those laws, which are occasioned by the interference of other causes.

I shall however just mention, previously to the statement of the necessary propositions, that though much mention is made of the *particles* of fluids, yet by this expression we only mean indefinitely small parcels of fluid; for we are not acquainted with the shape or size of those particles, nor indeed with that disposition which renders them so very moveable from each other. Our eyes, either naked

or when assisted by the most powerful microscopes, cannot discover any component particles of any fluid. Some small bodies are indeed to be seen in certain natural fluids, as in blood, milk, &c.; but those are not the parts which constitute the fluid; they are solid or compact small bodies, which swim in, or are mixed with the fluid.

*Proposition I. Every body, or system of bodies, endeavours to descend with its centre of gravity towards the centre of the earth, and that as near as it lies in its power.*

The truth of this proposition is fully manifested by all that has been already said relatively to the centre of gravity, and to the mechanical powers: but as it is the foundation of the doctrine of hydrostatics, it will be of use to render it still more familiar to the reader.

Thus if a solid body BD (fig. 1. Plate X.) be left at liberty, it will fall towards the ground, and if it happen to hit the ground with one end B first, in the oblique direction in which it is represented, it will not remain in the situation which is indicated by the dotted representation, but it will fall flat upon the ground, as at BC; for in that state its centre of gravity A will come as near as it possibly can to the ground, since the gravitating power will force the body to move on until a sufficient impediment is interposed between the centre of the Earth and the centre of gravity of the body.

Now

Now imagine that the abovementioned body be very soft, and it is plain that if the cohesion of its parts be less powerful than the gravity of those particles, the body will not remain in the situation ABC, but will spread itself very flat and close to the flat surface of the ground, in order that its centre of gravity may come as near as possible to the centre of the earth.

Farther, let the body AB, (fig. 2. Plate X.) consisting of two equal balls fastened to an inflexible rod AB, be placed upon the fulcrum D, whilst its centre of gravity is at C, viz. in the middle of the rod and it is evident that the end B will descend until the body remains in the situation of the dotted representation EG; for in that case its centre of gravity C is as low as the obstacles at D and G will permit it to descend.

The descent of this body AB may be prevented by applying a hand or some other obstacle at F; but in this case the obstacle at F will suffer a pressure upwards, which pressure is equal to the excess of the momentum of the end B above the momentum of the end A; viz. to the weight of B multiplied by BD, minus the weight of A multiplied by AD; for if that difference were added to the end A, the centre of gravity would then be removed from C to D, where it would be supported by the fulcrum D, and of course the two parts of the body on either side of D would balance each other; so that in this case one end of the body

presses

presses upwards, because the greater momentum of the other end tends downwards ; and the latter cannot act without producing the former.

*Proposition II. A fluid which is kept in any vessel open at top, will acquire, and will remain at rest with, a flat surface parallel to the horizon, as long as it is not disturbed.*

This is a natural consequence of the preceding principle ; for in that case the centre of gravity of the fluid will lie as low as it possibly can. Thus let ABDC (fig. 3. Plate X.) represent one side of a rectangular vessel containing water as high as EF, whose centre of gravity is G ; now we shall prove that when the surface of the water is flat and horizontal, as EF, then the centre of gravity of the water lies lowest ; but that if the water be elevated on any part of that surface, and of course lowered on any other part, then the centre of gravity will be removed to some place higher than G.

Imagine that the water be disposed in the situation DKBC, viz. that the portion KEH be removed to the place BH<sup>F</sup> ; and in this case the centre of gravity L of the quantity of water KDH FC remains in its original situation, whilst the centre of gravity of the quantity of water KEH has been removed higher, viz. from I to S. Now since the common centre of gravity of two bodies is in a straight line between the respective centres of gravity of those bodies ; therefore, the common centre of gravity of both the quantities of water formerly stood

stood at G in the line JS ; whereas it now stands at O in the line LS, viz. evidently higher than the level of G, which is the line zr.

This reasoning, which has, for the sake of brevity, been applied to one side of the vessel, may be easily adapted to any section of the water and vessel, as also to vessels of any shape, and to any irregularity which the surface of the water may be supposed to acquire ; for in any case the conclusion is exactly the same, namely, that the centre of gravity of a given quantity of some uniform fluid, like water, which is contained in an open vessel of any shape, stands at the lowest possible situation, - when the whole surface of the fluid is in the same horizontal line.

It is an evident consequence of this proposition, that if a vessel consist of two pipes perpendicular to the horizon, and open at top, as in fig. 4. Plate X ; or if it consist of various pipes communicating with each other, (however they may be inclined to the horizon, but open at top), as in fig. 5. Plate X. and a quantity of water, or of other fluid, be poured into any of them, the water will rise to the same horizontal line or level in all the pipes which communicate as above ; for in that case only the centre of gravity of the whole quantity of water will lie as low as the vessel can admit of.

Those persons who may think it strange that the fluid going down one pipe should drive a part of the fluid upwards in the other pipe, must consider

sider that this is analogous to the pressure upwards of the solid, fig. 2. Plate X. as explained in page 27; viz. the fluid is driven upwards in one pipe, in order that the greater quantity of fluid in the other pipe may descend lower down.\*

Propo<sup>1</sup>

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\* Though the application of prop. 2d. to the above-mentioned case of pipes, &c. be very obvious; yet to prevent any possible difficulty in the mind of the novice, I shall instance it in the case of fig. 4. by which example the attentive reader may be fully enabled to apply it to any other case.

GD and FC represent two equal cylindrical pipes open at top, communicating with each other at the bottom, and containing water as high as A.B; the height AD, or BC, being 10 feet; it is evident that the centre of gravity of all the water which is contained in those pipes must be at K, viz. five feet above DC, and midway between the two pipes; whilst the centre of gravity of the water in each pipe is at Y and Z respectively. Now suppose it possible to remove two feet height of water from the pipe GD into the pipe FC; then, because the pillar of water DE which remains in the pipe GD, is eight feet high, its centre of gravity must be at S, 4 feet above D; and because the pillar of water CF in the other pipe now is 12 feet high, its centre of gravity T must be six feet above C; so that the centre of gravity of the water in GD has been lowered as much as the centre of gravity of the water in FC has been elevated; hence the straight line ST must pass through the point K, which is the common centre of gravity of both the pillars of water when they were equal.

Proposition III. The pressure of the same fluid is in the proportion of its perpendicular height; and is exerted in every direction. So that all parts of the same fluid, at the same depth, press each other with equal force in every direction.

In fig. 5. Plate X. it is evident that the quantities of water in the different pipes press equally against each other; for if a quantity of water be removed from any one of those pipes, the surface of the water will descend to a lower level in all the other pipes; and that the pressure is exerted equally in every direction is proved by observing that, however the pipes are connected at B, the water rises to the same level in them all.

In order to prove that the pressure is exactly proportional to the perpendicular height of the water, let ABE, GHD, be (fig. 6. Plate X.) two cylindrical pipes of equal diameter, situated perpendicular to the horizon; and let them contain equal quantities of water, which of course must be

But now the quantity of water CF is to the quantity of water ED, as 12 to 8, or as 3 to 2; therefore (see p. 75. Vol. I.) the distance of their common centre of gravity O from S, must be to its distance from T, as 3 to 2, viz. it must be nearer to T than to S, or nearer to T than the point K is; for K is midway between S and T; therefore, by removing part of the water from one pipe to the other, the centre of gravity of the whole has been raised; hence that centre of gravity lies lowest when the surface of the water in both pipes is in the same level, or horizontal line, AB.

equally

equally high in both pipes, viz. AB equal to CD; and the pressures on the bottoms BE, ED must evidently be equal. Now let the water AFBE be poured into the other pipe, where it will occupy the space GHFC, so as to make the whole perpendicular height HD double the height CD. And it is also evident that the quantity of water GHFC must press as much upon the surface of the water FCED, as it did upon the bottom BE; therefore the pressure on the bottom ED is now double of what it was before, viz. a double perpendicular height occasions a double pressure. In the same manner it is proved that a treble perpendicular height occasions a treble pressure; or, universally, that the pressure is as the perpendicular height. And the same thing is evidently true with respect to any other uniform fluid.

Notwithstanding the evidence of this demonstration, some of my readers may still wonder that a small quantity of water, such as is contained in the pipe AB, (fig. 7. Plate X.) should balance the large quantity of water in the pipe DC; and to those it may be of use to see this property exhibited in another light.

Suppose then that the capacity of the cylindrical vessel EDC be equal to 100 times the capacity of the other cylindrical vessel AFB. Now if the water were to rise one inch above ED in the large vessel, it is evident that it would necessarily fall 100 inches below AF in the small vessel; so that

that the spaces, through which those two quantities of water move, or their velocities, are inversely as their quantities, or their weights: hence their momentums are equal, and of course they balance each other, in the same manner as the two weights R and Z of fig. 8. Plate X. balance each other, when the arms of the rod on either side of the prop S are inversely as the weights.

It is an evident consequence of this proposition, that the pressure on any determined part of the bottom, or of the sides, of any vessel containing a uniform fluid, like water, is equal to the weight of a pillar of that fluid having a base equal to that part of the bottom, or side, and the altitude equal to the perpendicular height of the fluid above it.

Whence we may calculate the pressures upon, and of course the strength required for, dams, pens, cisterns, aqueducts, dikes, flood-gates, &c. (1.)

Before

(1.) The practical application of this corollary to such surfaces as are parallel to the upper surface of the fluid, is easy and obvious; for we need only multiply the given surface by the perpendicular altitude of the fluid above it. Thus if it be required to determine the pressure upon two square feet of the flat bottom of a vessel which contains three feet perpendicular depth of water, we multiply 2 feet by 3, and the product is 6; viz. the proposed part of the bottom sustains a pressure equal to the weight of six cubic feet of water; but one cubic foot of water weighs about 1000 avoirdupoise

Before we proceed any farther, it is necessary to observe, that the surface of the water, or of any other fluid, has been said to assume a flat horizontal surface, or to come to the same horizontal line, in

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dupoise ounces; therefore the above-mentioned pressure is equal to 6000 ounces, or to 375 pounds.

But the application of it to oblique or curve surfaces is not equally obvious; for every point of such surfaces is at a different distance from the upper surface of the fluid: we shall, therefore, endeavour to elucidate it in a more particular manner; and for this purpose it will be necessary to premise the following proposition, which is demonstrated in an easy and perspicuous manner, as given by Mr. Cotes in his Hydrostatical Lectures.

*If any indefinitely small part or point of a surface, or number of surfaces, be multiplied by its perpendicular distance from any given plane; the sum of the products will be equal to the product of the whole surface, or number of surfaces, multiplied by the perpendicular distance of the centre of gravity of the single surface, or of the common centre of gravity of the whole number of surfaces, from the same plane.*

In fig. 17. Plate X. let any number of quantities  $a, b, c, d$ , represent as many weights, hanging at their centres of gravity,  $a, b, c, d$ , by the lines  $ao, bo, co, do$ , fixed to any horizontal plane  $o, o, o, o$ ; and let  $z$  be the common centre of gravity of all the weights, and  $zo$  its perpendicular distance from that plane: I say that  $a \times ao + b \times bo + c \times co + d \times do = a + b + c + d \times zo$ .

For let the common centre of gravity of the weights  $a, b, c, d$ , be the point  $x$ , and to the line  $xo$ , drawn parallel to the rest,

in such pipes as communicate together, on the supposition that the force of gravity acts in the direction of parallel lines; and such appears to be the case with small surfaces of water, as for instance,

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reft, let  $am$  and  $bn$  be perpendiculars. Then by the similar triangles  $mxa$ ,  $nxb$ , we have  $mx : nx :: (xa : xb :: ) b : a$ , by the known property of a centre of gravity. Hence  $a \times mx = b \times nx$ , or  $a \times \overline{mo} - \overline{xo} = b \times \overline{xo} - \overline{no}$ , or,  $a \times mo - a \times xo = b \times xo - b \times no$ : whence  $a \times mo + b \times no = \overline{a+b} \times \overline{xo}$ ; which was to be proved in the simplest case of the proposition.

Now let a weight  $x = a + b$ , be suspended by a line  $xo$ , in the common centre of gravity of  $a$  and  $b$ ; and likewise a weight  $y = x + c$ , in the common centre of gravity of  $x$  and  $c$ ; and also a weight  $z = y + d$  in the common centre of gravity of  $y$  and  $d$ : Then  $z$  is the common centre of gravity of all the weights  $a, b, c, d$ , first proposed.

Consequently, by what has been proved in the first case, we have  $a \times ao + b \times bo = x \times xo$ ; and likewise  $x \times xo + c \times co = y \times yo$ ; and likewise  $y \times yo + d \times do = z \times zo$ : consequently,  $a \times ao + b \times bo + c \times co = y \times yo$ ; and likewise  $a \times ao + b \times bo + c \times co + d \times do = (z \times zo =) \overline{a+b+c+d} \times \overline{zo}$ ; which was to be proved.

Hence if a surface or number of surfaces of any kind be considered as equally ponderous in every equal part, and as divided into indefinitely small parts, suspended by lines drawn from their centres perpendicularly to any horizontal plane; it is manifest that if every part be multiplied respectively into its perpendicular line, the sum of the products will be equal to the product of the whole surface multiplied

stance, a small pond, a cistern, &c. But since the force of gravity tends to the centre of the Earth, every point of the surface of the water, or of any other fluid, when quiescent, must be equidistant from that

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into the perpendicular distance of its centre of gravity from the said plane; and that this equality of the products will subsist even if the said lines be perpendicular to any plane, though not parallel to the horizon.

This being premised, the method of determining the pressure of a fluid upon any given surface becomes evident and general; for considering the upper surface of the fluid as the above-mentioned plane, in the first place we find the area of the given surface (by common mensuration); secondly, we find the centre of gravity of the same (by the rules of chap. VI. P. I.): then multiply the area of the given surface by the perpendicular distance of its centre of gravity from the surface of the fluid, and the product will express the pressure. Thus the pressure on the surface of an hemispherical vessel full of water, is equal to the product of its surface multiplied by its radius.

Thus also the pressure upon the side ABCD of the rectangular vessel, fig. 18. Plate X.; full of water, is equal to the product of the area ABCD multiplied by half the depth of the water; viz. by the distance of the centre of gravity E of the proposed surface from the surface of the water.

It appears from what has been said above, that the pressure of a superincumbent fluid on the side of a vessel, or, in general, on any surface which is not parallel to the surface of the fluid, must be unequally distributed over it. Thus, for instance; if through the centre of gravity E of the side ABCD,

that centre: hence that fluid must assume a spheroidal surface, like that of the Earth; and this curvature is both visible and measurable in large surfaces of water, as that of the sea.

Since

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A B C D, fig. 18. Plate X, an horizontal line be drawn, which divides that side into two equal parts; it is evident that the pressure on the lower half is greater than the pressure on the upper half, because the former lies deeper into the water. Therefore there must be an horizontal line lower than the middle E, which divides the side A B C D into two such unequal parts, as that the pressure of the fluid upon one of those parts be equal to the pressure of the fluid upon the other. Hence if the whole pressure of the fluid were collected upon that line, it would have the same effect upon the plane, as when it was distributed unequally upon it.

It may be likewise easily conceived, that in the last mentioned line there must be a point, in which if the whole pressure were collected, it would have the same effect upon the plane as when the pressure was unequally distributed all over it.

It follows, that if exactly against that point, but on the opposite side of the plane, a force be applied equal to the whole pressure of the fluid upon that plane, this force would exactly counteract that pressure, and the plane would remain perfectly at rest, viz. it would not incline to any side. Now that point in any surface is called *the centre of pressure of that surface*, and may be investigated by means of a fluxional calculation. But for this investigation, which goes rather beyond the limits of an elementary treatise, I must refer my

Since fluids press in every direction, and that pressure is as their perpendicular heights ; therefore, at the same depth, the particles of the fluid press equally against each other. Also, since equal bulks of a uniform fluid are of equal weight, therefore no motion can take place in a fluid without some external cause ; but if one parcel of the fluid becomes lighter or heavier than the rest, then that portion will ascend or descend in the fluid, giving way to other parcels of the fluid that are heavier or lighter than itself.

When the bottom, or one side of a vessel full of

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inquisitive readers to the works of other writers. It is necessary however to add the following observations.

In this case the plane, which sustains the pressure of the fluid, is supposed to be an inflexible plane, or the surface of a very substantial solid ; for if the plane be the thin side of a vessel, or any other very flexible substance, the pressure collected in one point would not produce the same effect as when it is distributed over the whole plane. It may be sustained in the latter case, whereas it might bend or burst the plane in the former.

Various writers have concluded, that if a plane immersed in a fluid be supposed to be extended until it cuts the surface of the fluid, and if that section be considered as the axis of motion of a pendulum whose bob, or suspended body, is the proposed plane ; the centre of oscillation of such a pendulum coincides with the centre of pressure of that plane. But Professor Vince shews, in his principles of hydrostatics, Sect. I. Prop. XII. that those points seldom coincide.

fluid is heated, the fluid which is contiguous to the heat, is thereby rarefied, viz. its bulk becomes enlarged, and of course it becomes lighter than an equal bulk of the same fluid which is not so rarefied; hence it ascends in it, &c.—And this is the cause of the motion which takes place in fluids that are heating or boiling.

The same thing which has been said of fluids in fluids, or of the parcels of a fluid, is applicable to solids, viz. a solid at any depth is pressed in proportion to the perpendicular altitude of the fluid over it; but as that pressure acts on every side, the body will not ascend nor descend in the fluid, unless its weight is smaller or greater than that of an equal bulk of the surrounding fluid.

If the immersed body be compressible, such as a bladder full of air, then the pressure of the superincumbent fluid, according to its perpendicular height, will be rendered manifest; for the deeper the body is conveyed, the more will its bulk be contracted.\*

If

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\* Sailors at sea frequently shew the following experiment: They cork an empty bottle, (viz. a bottle full of air), tie it to a rope, to which is added a leaden weight, and let the whole down into the sea to a certain depth; they then pull up the apparatus, and generally find that either the cork is driven into the bottle, or the bottle is broken. But if the experiment be tried with a bottle full of water, or of wine, and corked as before, no alteration

If, when a solid is immersed in a fluid, the pressure of the fluid on one side of the body be prevented, then the pressure on the other sides of it will be rendered manifest; and by this means a body actually heavier than an equal bulk of water, may be caused to be pressed upwards by the water; and, on the other hand, a body actually lighter than an equal bulk of water may be caused to be pressed downwards by the water.

Take a glass tube about 18 inches long, as AB fig. 20. Plate X. open at both ends, and let its lower end be ground quite flat and smooth. Let a brass plate C, a little larger than the diameter of the tube, be ground likewise very flat, and fix a little hook to its middle, to which a string D o must be tied. Place the brass plate against the aperture of the tube, and by pulling the string at D, keep

the

will take place. This difference of effect is owing to the bottle being full of a compressible fluid in the former case, and of a non-compressible fluid in the latter.

At the depth of 32 feet below the surface of the sea, a diver has been calculated to be pressed with the weight of about 28000 avoirdupoise pounds; yet as that pressure is distributed all over his body, and the human body consists mostly of non-elastic fluids or of solids, he does not feel any remarkable inconvenience from it.—This pressure is calculated in the following manner.

The surface of the body of a middle sized man is reckoned equal to about 14 square feet; therefore a diver situated 32

the plate tight against the tube. In this situation immerse the tube in the water, until the plate is below the surface to the depth of more than 8 or 10 times its thickness. Then if the string be let go, the plate will not fall off, but will remain adhering to the glass tube; the reason of which is, that now the water presses only against the under part of the brass plate. And, in fact, if water be poured into the tube, then the plate will be immediately separated from the tube, and will fall to the bottom of the vessel EF.

A brass plate *ac*, fig. 21. Plate X. very flat and smooth, must be cemented to the bottom of a vessel EF; a similar smooth brass plate, to which a large cork is cemented so as to form a compound body lighter than an equal bulk of water, must be laid upon the former plate, and in very close contact with

feet below the surface of the sea is pressed by a pillar of water whose base is 14 square feet, and altitude 32 feet. Now such a pillar contains ( $14 \times 32 =$ ) 448 cubic feet of water, and as a cubic foot of water weighs about 1000 avoirdupoise ounces; therefore the weight of such a pillar is ( $448 \times 1000 =$ ) 448000 ounces, or 28000 avoirdupoise pounds.

In this calculation the surface of the body of the diver has been considered as being all at an equal distance from the surface of the sea, which is not really the case: but at the depth of 32 feet the difference of perpendicular distance of the various parts of the body is not considerable; so that the result of the calculation is very near the truth, especially if the depth be reckoned from the middle of the body.

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it. Then by applying a hand, or a stick to the upper part of the cork, keep it down until the vessel EF be filled with water. This done, remove the hand or stick from over the cork, and it will be found that, though specifically lighter than water, the cork and brass plate will not ascend to the surface of the water. The reason of which is, that the water cannot in this case press on the lower surface of that brass plate. And in fact, if by means of the stick or hand, the upper brass plate be separated a little from the lower one, so that the water may enter between them, then the upper plate with the cork will immediately ascend to the surface of the water.

*Proposition IV. When fluids of different specific gravities mutually press against each other, their surfaces cannot lie in the same level; but their perpendicular altitudes above the level of their junction are inversely as their specific gravities.*

The weights of equal bulks of different bodies are called *their specific gravities*, or *their relative weights*. Thus, for instance, if you fill a vessel with water, and weigh it; then remove the water, fill it equally full with quicksilver and weigh it again, you will find it to weigh in the latter case 14 times as much as it weighed in the former\*: therefore the specific gravity of quicksilver is said to

\* 14 is rather greater than the truth. The real weight will be shewn hereafter.

be 14, whilst the specific gravity of water is said to be one; and so of the rest. Hence the weights of bodies, or their *absolute weights*, are expressed by the products of their bulks multiplied by their respective specific gravities; for, in the above-mentioned instance, if the weight of quicksilver is 14 pounds, when that of an equal bulk of water is one pound, it follows that 4 times that bulk of quicksilver must weigh 4 times 14, or 56 pounds; that 10 times that bulk of quicksilver must weigh 140 pounds; that twice that bulk of water must weigh twice one, viz. 2 pounds; and so forth.

Now let the part ECDF of the cylindrical bent tube, fig. 9. Plate X. be filled with quicksilver, the surface of which will come to the same level EF in both legs. Then suppose that one inch height of quicksilver, viz. GE, be removed from the pipe CS, and that instead of it fourteen inches of water, viz. GS, be added; it is evident that since quicksilver is fourteen times as heavy as water, the perpendicular pillar of water GS must press upon the surface of the quicksilver GV, as much as the perpendicular pillar of quicksilver EG: hence the pressure against the quicksilver in the pipe BD remaining the same, its surface must remain at F. But the surface of the water is at S, viz. 14 inches above the level GZ of the junction of the two fluids, whilst the surface F of the quicksilver is one inch above the said level. Therefore the perpendicular heights of those fluids above

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the level of their junction are inversely as their specific gravities.—The like reasoning may evidently be applied to all other fluids, and to vessels of any other shape: therefore the proposition is universally true.

*Proposition V. A body floating in a fluid displaces a quantity of the fluid, the weight of which is equal to the weight of the body.*

Thus the body DB, fig. 10. Pl. X. floating on the fluid FHG, weighs as much as the quantity of that fluid which would exactly fill up the space ABCE; for the body DB is kept in that place by the pressure of the surrounding water, which same pressure, previously to the immersion of the body, was just sufficient to keep in the same place a quantity of the same fluid equal to the space ABCE: therefore the weight of that quantity of the fluid is equal to the weight of the body.

The following consequences, or *corollaries*, are naturally deduced from this proposition.

1. If the same body be successively placed on fluids of different specific gravities, it will displace different quantities of those fluids; that is, it will sink deeper in the lighter than in the heavier fluid.

2. If the weight of the body be equal to that of an equal bulk of the fluid, then that body will remain at rest in any part of that fluid below the surface,

surface, and no part of the body will appear above the surface of the fluid.

3. If a body heavier than an equal bulk of a certain fluid, be placed on the surface of that fluid, it will sink with the excess of weight by which the weight of the body exceeds the weight of an equal bulk of the fluid. Thus, if a body which weighs three pounds be put in water, and a quantity of water equal in bulk to that body weighs two pounds; then the body will descend in the water with the force of one pound; the meaning of which is, that if that body be tied by means of a string to one scale of a balance, and be weighed, first out of the water, and then in water, as in fig. 11. Pl. X. it will be found to weigh three pounds out of the water, and one pound in water: whence it follows, that if the weight of a body be divided by that weight which it loses in water, the quotient shews its specific gravity; viz. it shews how many times that body, is heavier than an equal bulk of water.

4. If a body lighter than an equal bulk of a certain fluid be placed at the bottom of a vessel full of that fluid, that body will ascend with more or less force, according as the difference of weight between the body and an equal bulk of the fluid is greater or smaller; because a quantity of the fluid equal to it in bulk, but heavier than the body, will continually take its place, until part of the body projects above the surface of the fluid;

and

and only such a part of it will remain in the fluid, as can displace a quantity of the fluid whose weight equals the weight of the body. Therefore in order to keep that body below the surface of the fluid, you must press it with a weight equal to the difference between the weight of the body and the weight of an equal bulk of the fluid.

5. If a body be caused to float successively on two different fluids, the quantities of those fluids, which are displaced by that body, and likewise the parts of that body which are immersed in the two fluids, will be inversely as the specific gravities of those fluids. Thus, suppose that a solid body weighs 5 lbs. that an equal bulk of water weighs 10 lbs. and that an equal bulk of another fluid weighs 15 lbs. in which case the specific gravities of the solid body, of the water, and of the other fluid, are as 1, 2, and 3: Then that body, when floating upon water, will displace a quantity of water which is equal to one half of its bulk, and when floating upon the other fluid, it will displace a quantity of that other fluid, which is equal to one third part of its bulk. But one half is to one third, as 3 is to 2, and those numbers are inversely as the specific gravities of water and of the other fluid.

6. When a solid is floating upon a fluid, the part immersed is to the whole solid, as the specific gravity of the solid is to the specific gravity of the fluid; for when the specific gravity of the solid is equal

equal to that of the fluid, then the solid displaces a quantity of fluid equal in bulk to itself; when the specific gravity of the solid is the half of that of the fluid, then it displaces a quantity of fluid the bulk of which is equal to the half of its own bulk; and so forth.

7. All bodies retain their whole gravity when immersed in a fluid; but that gravity is either partly or entirely counteracted by the pressure of the fluid, according as the gravity of the immersed body is equal to, or different from, that of an equal bulk of the fluid.

*Proposition VI. If a lighter fluid rest upon a heavier, and a body whose specific gravity is greater than that of the upper, and less than that of the lower fluid, remain between them; the part of it which stands in the upper fluid is to the part of it which stands in the lower fluid, as the difference between the specific gravity of the lower fluid and the specific gravity of the body, is to the difference between the specific gravity of the upper fluid and the specific gravity of the body.*

The demonstrations of this and of the following propositions will be found in the notes; so that the reader may, according to his capacity, either examine them, or take the propositions for granted. (2.)

Cor.

(2.) Fig. 12. Plate X. represents a vessel which contains two fluids, whereof ADEF is the lighter, whose specific gravity

Cor. The part  $L$  is to the whole body, as the difference between the specific gravities of the solid and lighter fluid, is to the difference between the specific gravities of the heavier and lighter fluids. (3.)

### Proposition

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Let  $a$  be the specific gravity of the lighter fluid;  $b$  the specific gravity of the heavier fluid;  $c$  the specific gravity of the body;  $U$  the upper part of the body which remains in the fluid;  $L$  the lower part of the body which remains in the fluid.

It has been shewn in cor. 3. of prop. V. that if the weight of a body be divided by the weight which it loses in a fluid (which is the weight of an equal bulk of that fluid) the quotient will express the specific gravity of that body in comparison with that of the fluid, which will be called unity. Therefore if the weight of the body out of the fluid be divided by its specific gravity, the quotient will be the weight of a quantity of that fluid equal in bulk to the body. Hence it appears that the weight of the body is  $c \times \overline{U+L}$ , that the weight of that quantity of the lower fluid which is displaced by the part  $L$ , is  $Lb$ , and the weight of that quantity of the upper fluid which is displaced by the part  $U$ , is  $Ua$ : therefore  $Lb + Ua = c \times \overline{U+L} = Uc + Lc$ . Hence  $Lb - Lc = Uc - Ua$ ; or  $L \times \frac{b-c}{c} = U \times \frac{c-a}{c}$ : therefore  $U : L :: b - c : c - a$ .

(3.) The last analogy, by inversion and composition, becomes  $L : L + U :: c - a : b - a$ .

Considering that we are surrounded by a thin and invisible fluid called *air*, (as will be more particularly shewn in the sequel) in which we constantly move and live; it follows that a body when weighed in the common way, that is, in air, weighs less than if it were weighed in *vacuo*, viz.

**Proposition VII.** If two fluids be mixed together, the bulk of the heavier fluid is to the bulk of the lighter, as the difference between the specific gravities of the mixture and of the lighter fluid, is to the difference between the specific gravities of the mixture

viz. where there is no air; "also, that if any substance float upon the surface of a fluid in vacuo, upon admitting the air, the floating body will rise higher above the surface, so that the proportion of the part immersed to the whole will be somewhat less than before. The difference of the parts of a solid immersed in a fluid, when in vacuo, and in open air, may be estimated in general thus." — *Atwood's Descrip. of Experiments for a Course of Lectures.*

Let  $m$  = the magnitude of the solid body;

$s$  = its specific gravity;

$A$  = the part immersed when in open air;

$B$  = the part immersed when in vacuo;

$a$  = the specific gravity of the fluid in which the solid is immersed;

$g$  = the specific gravity of air.

Then (Cor. 6. of Prop. V.)  $B : m :: s : a$ ; and  $B = \frac{ms}{a} =$  to the part immersed in the fluid when no air is over it.

By the corollary to the last Prop.  $A : m :: s - g : a - g$ ; and  $A = m \times \frac{s - g}{a - g} =$  to the part immersed in the fluid when the air is over it, as in the common way. And the difference of those parts  $= B - A = \frac{ms}{a} - \frac{m(s - g)}{a - g} = \frac{m \times sa - sg - sa + ag}{a^2 - ag} = \frac{mg \times a - s}{a^2}$  nearly.

ture and of the heavier fluid. Then as the bulk of the heavier fluid, multiplied by its specific gravity, is to the bulk of the lighter fluid multiplied by its specific gravity, so is the weight of the heavier fluid to the weight of the lighter fluid (3).

The same thing must be understood of two

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The specific gravity of air (viz.  $g$ ) is about 0,0013; hence, by making the computation, it will appear that the existence of the air over a fluid in which a solid floats, produces a very small difference with respect to the part of the solid which is immersed in the fluid; so that it needs not be regarded, unless the utmost precision be required; in which case the actual specific gravity of the air, as indicated by the barometer, must be taken into the computation; for the gravity of the air is continually varying, and its actual quantity is shewn by the barometer, as will be explained hereafter.

It follows likewise, that if two bodies, of different specific gravities, balance each other in a pair of scales, their weights are not exactly equal; for if the air were removed, that body whose specific gravity is least would preponderate.

(3.) Let  $A$  and  $B$  represent the bulks of the two fluids,  $a$  and  $b$  their specific gravities, and  $c$  the specific gravity of the compound. Then the weight of the compound is represented by  $c \times \overline{A+B}$ ; the weight of  $A$  is represented by  $A a$ , and the weight of  $B$  is represented by  $B b$ ; therefore  $A c + B c = A a + B b$ ; and  $B c - B b = A a - A c$ ; that is,  $\overline{c-b} \times B = \overline{a-c} \times A$ ; consequently  $A : B :: c-b : a-c$ .

solids

solids intermixed together, such as an alloy of two different metals, &c.

This proposition is, however, true only when the bulk of the compound is equal to the sum of the bulks of the two components previously to their being mixed, which seldom is the case; experience shewing (as will be particularly mentioned in the sequel) that when two or more bodies are mixed together, a sort of incorporation, and sometimes an expansion, frequently takes place, which is attended with a diminution or increase of bulk; thus, a pint of spirit of wine mixed with a pint of water, forms a compound which measures less than two pints. And a cubic inch of tin incorporated, by means of fusion, with a cubic inch of lead, will form a mass which measures more than two cubic inches.

When such increase or decrease of bulk does not take place, then we may, by the last proposition, find out the weights of two ingredients which form a compound body, having given the specific gravities of the ingredients, and of the compound.

## CHAPTER III.

## OR THE SPECIFIC GRAVITIES OF BODIES.

IT has been already mentioned that the specific gravity of a body is the proportion which its weight bears to the weight of another body of equal bulk. Thus the specific gravity of mercury is said to be to the specific gravity of water as 14 to one; the meaning of which is, that if a quantity of mercury, which exactly fills a certain vessel, and a quantity of water which likewise exactly fills the same vessel, be weighed separately, the former will be found to weigh 14 times as much as the latter; so that if the water weighs one pound, or one ounce, &c. the mercury will be found to weigh 14 pounds, or 14 ounces, &c.— Thus also the specific gravity of mercury is to the specific gravity of zinc as two to one; viz. if a cubic inch, or a certain vessel full, of mercury weigh 14 pounds, a cubic inch, or the same vessel full, of zinc will be found to weigh 7 pounds. Or if the former weigh 100 grains, the latter will be found to weigh 50 grains; and so on.

But though bodies may be thus compared indiscriminately together, yet conveniency has established the custom of comparing all bodies with water, the specific gravity of which is reckoned one,

one, or unity; so that, speaking of the above-mentioned bodies, the specific gravity of mercury is said to be 14, and that of zinc, to be 7; meaning that equal quantities of water, of mercury, and of zinc, weigh respectively 1, 14, and 7, be they pounds, or ounces, or grains, or any other weights. Nor does this mode of expressing the specific gravities alter the proportion between any two or more bodies; for instance, it has been said above, that the specific gravity of mercury is to that of zinc as two to one, and by the last expression those specific gravities have been stated as 14 and 7; but those two numbers are to each other exactly in the ratio of two to one.

The reasons for which water has been generally adopted as the standard with which all other bodies are compared, are, 1st, that by weighing the same body out of water and in water, the specific gravity of that body may, in general, be more easily ascertained than by any other means; and 2dly, that water of the same purity and of the same specific gravity, may be easily procured in every country.

But the specific gravity of water is liable to be altered by two causes, viz. by the admixture of other substances, and by an alteration of temperature; — water, for instance, at 100° of temperature, is lighter than water at 60°; and still lighter than water at 40°. Therefore the water, which is to be used for the purpose of ascertaining the

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specific gravities of bodies, must be free from heterogeneous substances, and must be used always at the same degree of temperature.

Distilled water, and rain water, are sufficiently pure, and equally useful for the above-mentioned purpose, as they have not been found to differ in specific gravity.

The most natural way of determining the specific gravity of bodies is to weigh in a pair of scales, or by means of a steelyard, bodies of different sorts, but of precisely the same dimensions; and this, indeed, is a very good practical method for fluids, which may be put successively into the same phial, &c.; but the difficulty of forming solids exactly of the same dimensions is so very great, that their specific gravities are generally determined by weighing each body both out of water and in water, in the manner which will be particularly described in this chapter; excepting some powdery substances, which, in this respect, may be treated like fluids.

It appears, therefore, that a common pair of scales, or balance, is the principal instrument which is required for determining the specific gravities of bodies. It only requires to have a hook affixed under one of the scales. This balance, when in use, might be held in the operator's hand: but as those experiments require a certain time, and much accuracy, therefore it is advisable to have them set upon a stand, such as is represented in fig.

fig. 14. of Plate X. The whole apparatus, then, for determining specific gravities, which goes under the name of the *Hydrostatical Balance* and its *apparatus*, consists of the following parts. A balance, such as ABCD, fig. 14. Plate X. which should be so sensible as to turn at least with the 20th part of a grain when each scale is loaded with a weight of two or three ounces. An accurate set of weights, especially of grains, such as weights of 10 grains and of 100 grains, besides the single grains; it being much more commodious to make the computation entirely in grains, or at most in ounces and grains, than to be encumbered with weights of different denominations. A glass jar E, about 7 or 8 inches high, which is to contain the distilled or rain-water. A glass ball, of about an inch, or an inch and a half in diameter, with a bit of fine platina wire, about three inches long, affixed to it\*. A small glass bucket G, with

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\* This ball may be either of solid glass, or of hollow glass partly filled with quicksilver, or with some other heavy substance. In the latter case it generally has a short perforated stem, into the perforation of which the platina wire is fastened with cement. But if it be a solid glass ball, a hole of about  $\frac{1}{3}$  th of an inch in length must be drilled in it, wherein the wire is to be fastened. For the sake of expedition in making the computation, it would be proper to make this glass ball of a certain weight expressible by a round number; for instance, of 100, or 500, or 1000 grains.

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a glass handle. A small phial or two, as H; viz. of such a shape as to admit of their being easily filled, emptied, and cleaned. And a thermometer I.

This hydrostistical balance and apparatus is commonly made by the philosophical instrument-makers of a very compact form, so as to admit of its being packed up in a pretty small box; but when in use, it must be set upon a table, as is represented in fig. 14, where, it must be remarked, that the balance may be moved a little way up or down, either by means of the string which goes along the stand, in the common way, or by some other mechanical contrivance which needs not be particularly described.

We shall now proceed to state the practical methods of determining the specific gravities of bodies of various species; which methods are nothing more than practical applications of the Propositions of the preceding chapter, as will appear by observing at the end of the Rules, the quotation of the Propositions upon which those rules depend.

*Problem I. To ascertain the specific gravity of a pretty large solid, which is heavy enough to sink in water.*

*Rule.* Suspend the solid by means of as slender a thread as may be just sufficient to hold it, to the hook under the scale C, so as to hang at the distance of six or seven inches below that scale, and

by putting weights in the opposite scale D, find out its exact weight in air, that is out of the water. Then place the jar E, about three-quarters full of rain or distilled water, just under the scale C, which is the case actually represented in the figure; let the solid body be immersed in the water, and either by removing some of the weights from the scale D, or by putting weights in the scale C, find out its exact weight in water. Subtract the latter weight from the former, and note the remainder. Lastly, divide the weight of the solid out of the water by that remainder, and the quotient will express its specific gravity. (Prop. V.)—See the precautions which follow the example.

*Example.* A piece of silver was found to weigh in air (that is, out of the water) 136 grains, and in water 123,73 grains. The latter weight being subtracted from the former, there remained 12,25 grains. Lastly, 136 was divided by 12,25, and the quotient 11,091 expressed the specific gravity of the piece of silver.

Before we proceed any farther, it is necessary to prevent any possible mistake, by the statement of the following

*General precautions.* The water in which the solid is to be weighed, besides its being either distilled or rain water, must be quite clean.—Its temperature, as well as that of the solid, must be as near as possible to 62° of Fahrenheit's thermometer,

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meter; for which purpose the ball of the thermometer must be placed in the water, and the temperature is adjusted by the addition of hot or cold water.—If the solid body be soluble in water, or if it be porous enough to absorb any water, then it must be varnished, or smeared over with some oily or greasy substance; but in that case some allowance must be made on account of the varnish, &c.—When the solid is weighed in water, its upper part ought to be a little way below the surface of the water; for instance, about an inch; and it must by no means be suffered to touch the sides or bottom of the jar.—Care must be had that no bubbles of air adhere to the solid under water; for they would partly buoy it up. These may be easily removed by means of a feather.—The solid must be of a compact form, and free from accidental or artificial vacuities, so as not to harbour any air; for otherwise its specific gravity cannot be ascertained by weighing in water, &c. Thus a piece of silver, which is much heavier than water, may be formed into a hollow sphere, which will appear to be much lighter than water; for if this sphere were immersed in water, it would displace a quantity of water which is equal not only to the silver, but also to the space which is contained in the sphere\*.—These precautions must be attended

to

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\* It is for this reason that a ship might be made of iron, or of copper, or, in short, of any substance whose specific gravity

to in the practical performance of the preceding as well as of the following problems of this chapter, as far as they may be concerned in them.

*Problem II.* To ascertain the specific gravity of solids, or compact bodies, that are sufficiently heavy to sink in water, which are not soluble in that fluid, but are too small to be tied by means of a thread.

*Rule.* Suspend the glass bucket G by the interposition of a thread, to the hook of the scale C, and find its weight in air; then place the substance, which is to be tried, in it, and weigh it again. The former weight subtracted from the latter leaves the weight of the substance in air. This being done, the same operation must be repeated in water; that is, let the loaded bucket be weighed in water, then remove its contents, and weigh the bucket alone in water. Subtract the latter weight from the former, and the quotient is the weight in water, of the substance under examination. Having thus obtained the weights of that substance in water and out of water, you will then proceed according to the preceding problem; viz. subtract its weight in water from its weight in air, and note the remainder. Divide its weight in air by this remainder, and the qu-

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gravity far exceeds that of water; and yet it would float as well as a ship which is made of wood, in the usual way.

tient

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tient will express its specific gravity. (Prop. V.) — Observe the general precautions at the end of Problem I. p. 57.

By this means the specific gravity of diamonds and other small precious stones, as also of grains of platina, of filings of metal, of mercury, &c. may be ascertained.

*Example.* The glass bucket being suspended from the hook of the scale C, was counterpoised by weights in the opposite scale D. Some gold-dust was then placed in it, and by adding more weights into the scale D, its weight (viz. of the gold-dust alone) was found to be 460,6 grains. The loaded bucket was then weighed in water, and was found to weigh 736,1 grains; and after having removed the gold-dust from the bucket, the latter by itself was found to weigh in water 300 grains; which being subtracted from 736,1, left 436,1 grains for the weight of the gold in water. Then this weight of the gold in water (viz. 436,1) was subtracted from its weight in air (viz. 460,6) and the remainder was 24,5. Lastly, the weight of the gold in air, viz. 460,6 was divided by the remainder 24,5, and the quotient 18,8 expressed the specific gravity of the gold-dust.

*Problem III.* *To ascertain the specific gravity of a solid body lighter than an equal bulk of water, viz. such as will not sink in it.*

*Rule.*

*Rule.* Take another body of a compact form, but much heavier than an equal bulk of water, so that when this body is connected with the body in question, they may both sink in water. This being prepared, ascertain the weight of the lighter body in air, and the weight of the heavier body in water. Then tie, by means of thread, both bodies together, but not so closely as to exclude the water from, or to harbour bubbles of air, between them; and weigh them both in water. Now since the heavy body is partly buoyed up by the lighter body, the weight of both in water will be less than the weight of the heavier body alone. Subtract the former from the latter, and add the remainder to the weight of the lighter body in air; for this sum is the weight of a quantity of water equal in bulk to the lighter body. Therefore the weight of the lighter body in air must be divided by the last-mentioned sum, and the quotient will express the specific gravity of the lighter body. (Prop. V. Cor. 3, and 4) — Observe the general precautions at the end of Prob. I. p. 57.

*Example.* A piece of elm, being varnished in order to prevent its absorbing any water, was found to weigh in air 920 grains. A piece of lead, which was chosen for this purpose, was found to weigh in water 911,7 grains. The piece of elm and the piece of lead were tied together, and being suspended from the hook of the scale C,

&c.

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&c. in the usual manner, were found to weigh in water 331,7 grains, viz. 580 grains less than the lead alone; therefore 580 was added to 920 (viz. to the weight of the elm in air) and made up the sum of 1500. Lastly, 920 was divided by 1500, and the quotient 0,6133 expressed the specific gravity of the piece of elm.

It is almost superfluous to observe, that the specific gravities of bodies that are lighter than water, are less than unity.

Problem IV. *To ascertain the specific gravities of small bodies (such as saline powders, &c.) which are soluble in, or absorb, water, and are not capable of being varnished.*

Rule. The substance in question must be reduced into fine powder, unless it be already in that shape. Take a clean glass phial, such as H, fig. 14, put it in one of the scales of the balance, and counterpoise it by placing weights in the opposite scale; then fill the phial with the powder in question, ramming it as close as possible, and quite up to the top. This done, replace the phial in the same scale in which it stood before, and by adding more weights in the opposite scale, find out the exact weight of the powder alone. Now remove the powder from the phial, fill the latter with distilled or rain water, and placing it in the scale as before, ascertain the weight of the water alone. By this means you have the weights of equal quantities of the powder and of water, which

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are exactly as their specific gravities; but the specific gravity of water is not in this case expressed by unity; therefore say, as the weight of the water is to the weight of the powder, so is unity to a fourth proportional, which is the specific gravity of the powder when that of water is reckoned unity; that is, divide the weight of the powder by the weight of the water, and the quotient will express the specific gravity of the powder.

In certain cases the saline substances or other small bodies, if the reducing them to powder be objected to, may be weighed in the bucket, according to Problem II. but instead of water they must be weighed in some other fluid, in which they are not soluble, and whose specific gravity is already known; for the specific gravities thus found may be easily referred to that of water.

*Example.* The phial H full of a certain salt was found to weigh 630 grains (meaning the salt alone, independent of the phial) and the same phial full of rain-water was found to weigh 450 grains, (viz. the water alone); therefore 630 was divided by 450, and the quotient 1,4 expressed the specific gravity of the salt.

*Problem V. To ascertain the specific gravities of fluids.*

*Rule.* This may be done either by the method last-mentioned, which indeed is the most proper, it being the most accurate, for nice experiments; or in the following manner:

Suspend

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Suspend the glass ball F, fig. 14, or a piece of metal, to the hook of the scale C, and find successively its weight in air, its weight in water, and its weight in any other fluid you wish to try. Subtract its weight in water from its weight in air, and the remainder is its loss of weight when weighed in water. Also subtract its weight in the other fluid from its weight in air, and the remainder is its loss of weight in the other fluid. Now those two last weights are exactly as the specific gravities of the two fluids respectively. But the specific gravity of water is not, in this case, expressed by unity; therefore say, as the loss of weight in water is to the loss of weight in the other fluid, so is unity to a fourth proportional; that is, divide the loss of weight in the other fluid by the loss of weight in water, and the quotient will express the specific gravity of the other fluid.

For this purpose a glass ball with a bit of platina wire, are preferable to other substances, because amongst all the variety of fluids there are fewer that have any action upon glass and platina than upon any other solid; yet they are corroded by one or two fluids, and therefore when these are to be tried, the method of Problem IV. must be adopted; but the phial must consist of such a substance as is not liable to be corroded by the fluid in question; or the glass phial may be lined in the inside with a film of bees-wax, which is easily done

done by warming the phial; for this film will prevent its being corroded.\*

*Example.* A glass ball which weighed 100 grains in air, was found to weigh 60 grains in water, and 70 grains in another fluid; so that the loss of weight in water was 40 grains, and the loss of weight in the other fluid was 30 grains; therefore 30 was divided by 40, and the quotient 0,75 expressed the specific gravity of the other fluid.

The knowledge of the specific gravities of bodies is of the utmost consequence in philosophy, and in other sciences, as also in the several arts which depend on those sciences. Independent of those bodies which are pretty uniform, and whose specific gravities are well known, it frequently happens in chemistry, in the practice of several arts, and in some departments of civil society, that the specific gravities of various bodies, especially of compounds, must be actually ascertained on particular specimens. The strength and activity of divers chemical articles is accompanied with a proportionate degree of specific gravity; there-

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\* The specific gravity of air, and other elastic fluids analogous to air, is ascertained by first filling a phial with water and weighing it, then filling the same with the elastic fluid in question, and weighing it again, after the manner of Problem IV.; but the phial which is necessary for the purpose of confining elastic fluids, as also the mode of filling it, will be described hereafter.

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fore the knowledge of the latter is used as an indication of the former. The strength of spirits is determined both in distilleries, and by the officers of the excise, from their specific gravities. The assayers and the refiners of silver and gold frequently make use of the same means for determining the quality of their articles, and so forth.

This extensive use of the knowledge of specific gravities has produced a variety of contrivances, under the names of *Effay instrument*, *Hydrometer*, *Areometer*, *Gravimeter*, and *Pese-liqueur*, for the purpose of ascertaining the specific gravities of different bodies in an expeditious manner.

The construction of all those instruments depends upon the principle of the 5th Proposition of the preceding chapter, viz. that if a body whose specific gravity is less than that of certain fluids, be caused to float successively upon those fluids, it will sink deeper into the lighter than into the heavier fluid. Or that a greater addition of weight is required to keep the same part of the floating body below the surface of a heavier, than of a lighter, fluid.

The simplest hydrometer is represented in fig. 13. of Plate X. It consists of a graduated rod or stem, CA, about 4 inches long, which is fixed to the bulb A. From the lowest part of A another stem proceeds a short way, and terminates in a smaller bulb B. The bulb B is partly or entirely filled with some metallic substance, generally quicksilver, which

which answers two purposes; it renders the instrument just heavy enough to sink as far as some part of the stem CA below the surface of the fluid which is to be tried by it; and it serves to keep the instrument upright in the fluid; hence it is placed, as ballast, in the lowest part of the instrument.

Now when the specific gravity of a fluid is to be determined, the fluid is put into a glass jar, or other convenient vessel, and the hydrometer is set to float in it; then the specific gravity of the fluid is indicated by the number of the divisions of the stem AC which remain above the surface of the fluid; or (which amounts to the same thing) by those which remain below that surface; those divisions being made, by trial and adjustment, to represent parts of the whole bulk of the instrument. Suppose, for instance, that the bulk of the whole instrument be equal to 1000 cubic tenths of an inch, and that each of the divisions of the stem represents one of those parts. Then if this instrument be placed first in one fluid and then in another, and if it be found to sink as far as the 40th division (counting from the top) in one fluid, and as far as the 30th in the other fluid, it is evident that of the 1000 parts of the bulk, 960 have been sunk in the former fluid, and 970 in the latter; therefore, since the specific gravities of those fluids are inversely as the parts immersed, the specific gravity of the former is to that of the latter as 970 is to 960. If water be one of the

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fluids, for instance the former; then say, as 970 is to 960, so is one to a fourth proportional, which is the specific gravity of the other fluid when that of water is called unity. But the divisions on most of those instruments are numbered so as to indicate immediately the specific gravity of a fluid in comparison with that of water, which is reckoned one.

Hydrometers of the above-mentioned sort have been made of glass for such fluids as corrode metals; and of metal, which is more durable, for such fluids as have no action upon it. But its peculiar imperfections are two in number; 1st, It can serve only for those fluids which differ very little in specific gravity; for if the divisions of the stem represent small portions of the bulk of the instrument, then the whole length of the stem will likewise represent no great part of the whole bulk; hence very little difference of specific gravity can be indicated by all the divisions which are upon it; and if the divisions represent considerably large portions of the instrument, then the instrument will not indicate small differences of specific gravity. 2dly. The inequalities of the stem, and the small quantity of fluid, which in the common manner of using the instrument can hardly be prevented from adhering to that part of the stem which is just above the fluid, render it inaccurate in a greater or less degree.

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The removal of the first of those imperfections has been attempted either by adapting different stems to the same instrument; so that a heavier or a lighter stem might be put on, according to the nature of the fluid under examination; or by affixing certain weights to the instrument, and altering the value of the divisions accordingly.

The second imperfection has been removed by removing the divisions from the stem, and indeed by this means the first imperfection is in great measure removed; viz. the stem contains one mark about its middle, and the instrument is caused to sink always to that mark in different fluids, by the addition of different weights. Then the specific gravities are indicated by those weights.

The weights in some hydrometers are screwed to, or simply laid in a cup fit to receive them at the bottom of the instrument. In others the weights are placed in a cup which is fixed on the top of the stem, and which of course remains out of the fluid. But as the last method is apt to render the instrument top-heavy; therefore some of them have been constructed with two cups, viz. one at top and another at their lower part; and proper weights are to be placed in both, viz. the coarsest or largest in the lower, and the minutest in the upper cup.

Such instruments have also been used for determining the specific gravities of small solids. In

this case the solid is placed in the lower cup, and suitable weights are put into the upper cup.

Another instrument has also been used for expeditiously determining the specific gravities of fluids. It consists of a series of glass bubbles, increasing and decreasing in specific gravity from the standard fluid, in a known ratio. When a fluid is to be tried, those balls, which are all numbered, must be placed successively in the fluid, and it will be found that some of them will sink to the bottom of the vessel, whilst others will remain on the surface of the fluid; but that bubble which is precisely of the same specific gravity with the fluid, will remain in any part of it, without shewing any tendency either to ascend or to descend.

All those instruments must be reckoned inferior to the hydrostatical balance and apparatus, and that on various accounts, which will easily occur to any reflecting mind. Expedition of operation, and portability, are the only circumstances which have recommended them. But the use of the balance is by no means long and intricate; and it is unquestionably the least equivocal. With respect to portability, it must be observed that no single hydrometer, even of the best sort known, can be used for ascertaining the specific gravities of all sorts of bodies; and if many of them must be had in readiness, then the bulk of them all will more than equal that of a tolerably useful balance and apparatus. Therefore we may conclude with affirming,

that

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that the hydrostatical balance and apparatus is upon the whole the most accurate, the most durable, and the most portable apparatus for the purpose of ascertaining specific gravities in general; and that the use of hydrometers may be recommended to such persons only as are obliged to try a great variety of fluids which do not vary much in gravity; viz, to distillers, to officers of the excise, &c.

Thus far I have endeavoured to give a short but comprehensive account of the instruments, which, besides the balance, have been contrived for the purpose of ascertaining specific gravities. A particular description of them all is incompatible with the nature and limits of this work. But if the reader be desirous of examining the particular constructions and uses of such instruments, he may consult the books which are mentioned in the note\*.

In determining specific gravities of bodies, different experimenters have used water of various, and sometimes of unknown temperatures; generally how-

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\* Boyle's Works, quarto edition of 1772, vol. IV. p. 204.—Phil. Transactions, vol. 36, vol. for 1793, p. 164.—Memoirs of the Manchester Society, vol. I.—Ramsden's Account of Experiments to determine the Spec. Grav. of Fluids; London, 1792.—Annales de Chimie, vol. 21.—Baumé's Elem. de Pharmacie.—Nicholson's Journal of Nat. Phil. No. I. III.—De Prony's Architecture Hydraulique, from § 614 to § 626.

ever, between the 50th and 65th degree of Fahrenheit's thermometer. But the best tables of specific gravities have been formed at the temperature either of about  $55^{\circ}$  or  $60^{\circ}$ .

A considerable difference does frequently appear in those tables between the statements of the specific gravities of the same bodies. This difference sometimes affects even the first decimal figure; in one table, for instance, we find that a certain body is 2,135, and in another table that it is 2,245. It is evident that this difference cannot be attributed to the different specific gravities of water at those temperatures; for that difference will not affect even the third decimal figure; but it must be attributed to other causes, the principal of which are the imperfection of the instruments with which the bodies are weighed, and the various qualities of the bodies themselves, which are occasioned by innumerable and often apparently trifling circumstances. Hence it follows that in forming a table of specific gravities the greatest care should be had to attain the utmost degree of accuracy; but in the use of such a table, some latitude must be allowed to the possible error in the statement of the specific gravities, in proportion as the constitutions of the bodies are more or less variable.

The following table has been formed by comparing the best tables of specific gravities now extant; by consulting the works of the best authors who have treated of particular substances; and by repeating

repeating several of their experiments. But after all, it must be acknowledged, that the difficulty of reconciling the different discordant statements, and of obtaining genuine specimens for actual experiments, is so very great; that the utmost diligence will not be sufficient to obtain certainty and precision\*. The reader will find the substances arranged in the following manner. The metallic substances occupy the first place; these are followed by the earths and stones; then come the inflammable, the vegetable, the animal, and lastly the fluid substances.—When a substance is stated with two specific gravities, the meaning is, that the specific gravity of that substance is various, viz. some

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\* If the reader be desirous of examining this subject in a more particular manner, he may consult Dr. Davis's excellent Paper on Specific Gravities, in the Phil. Trans. vol. XLV. p. 416; or in the Abridg. vol. X. p. 206. This paper contains all that which had been done previous to the year 1747, relative to the subject.—M. Brisson's Tables of Specific Gravities.—M. de Prony's Archit. Hydr.—Mr. Gilpin's excellent Tables of the weights, &c. of mixtures of spirit and water in different proportions in the Phil. Trans. for the year 1794, page 275.—Kirwan's Mineralogy, second edit.—I do not refer the reader to a vast number of other tables, which are either less correct, or copied from the above-mentioned works. With respect to the gravity of air under different degrees of pressure, as also of heat, &c. he may peruse a most valuable paper of Col. Roy, in the Phil. Trans. vol. LXVII.

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	Spec. Grav.
Mercury, or Quicksilver*	at 32° of heat - - - - 13,619
	at 60° of heat - - - - 13,580
	at 212° of heat - - - - 13,375
Silver	fine, simply fused - - - - 10,474
	the same hammered - - - - 10,511
	sterling, or standard, containing 11 oz. 2 dwt. of fine silver in the pound troy; simply fused 10,200
	of the standard of the French coin in the year 1780, simply fused 10,047
	the same coined - - - - 10,408
Copper	simply fused† - - - - 7,788
	the same hammered - - - - 8,878
Brass, being a compound metal, varies between	7,600 8,800

\* The specific gravity of mercury varies a little with various specimens; but the proportion at different degrees of heat is nearly the same; the bulk of mercury increasing by the quantity 0,000102 for every degree of heat; its bulk at 32° being called one or unity.

+ Such is the usual specific gravity of copper, reckoned pure; but it is frequently found of superior gravity. Bergman found the specific gravity of Swedish copper to be 9.3243; but this may possibly be a mistake; for he likewise sets the specific gravity of iron at 8,3678, which is considerably higher than the best statements.

Iron

Of the Specific Gravities of Bodies. 77

	Spec. Grav.								
fused, but not hammered - - -	$\left\{ \begin{array}{l} 7,200 \\ 7,600 \end{array} \right.$								
forged, in the form of bars - - -	7,788								
Iron      in the state of	<table border="0" style="margin-left: 20px;"> <tr> <td>steel soft - - - -</td><td style="text-align: right;">7,833</td> </tr> <tr> <td>steel hammered - - -</td><td style="text-align: right;">7,840</td> </tr> <tr> <td>steel hardened in water*</td><td style="text-align: right;">7,816</td> </tr> <tr> <td>steel hammered, and then hardened in water - - - -</td><td style="text-align: right;">7,818</td> </tr> </table>	steel soft - - - -	7,833	steel hammered - - -	7,840	steel hardened in water*	7,816	steel hammered, and then hardened in water - - - -	7,818
steel soft - - - -	7,833								
steel hammered - - -	7,840								
steel hardened in water*	7,816								
steel hammered, and then hardened in water - - - -	7,818								
the purest from Cornwall, simply fused† - - - - -	$\left\{ \begin{array}{l} 7,170 \\ 7,291 \end{array} \right.$								
Tin      the same hammered - - - - -	7,299								
of Malacca, simply fused - - - -	7,296								
the same hammered - - - - -	7,306								
Lead, whether hammered or not - - -	$\left\{ \begin{array}{l} 11,445 \\ 11,352 \end{array} \right.$								
Zinc, simply fused - - - - -	7,190								

\* The expansion of steel in hardening, besides its being indicated by the decrease of specific gravity, is also decisively shewn by the following experiment of Mr. Robert Pennington.—A piece of steel which when soft measured in length 2,769 inches, after being hardened by plunging it red-hot in cold water, was found to measure 2,7785; and after having been let down to a blue temper, it measured 2,768 inches.

+ Gellert asserts that the specific gravity of the tin of Gallicia in Spain is 7,063.

Antimony,

Spec. Grav

Antimony, in a metallic state, simply fused { 6,624  
6,860

Bismuth, in a metallic state, simply fused { 9,756  
9,822

Cobalt, in a metallic state, simply fused { 7,645  
7,811

Smalt, or blue glass of cobalt - - - - 2,440

Nickel, of the purest sort - - - - { 7,000  
9,000

Sulphurated nickel, or the mineral called  
*kupfer nickel* by the Germans - - - 6,620

Manganese, in a metallic state - - - - 6,990

Arsenic, fused\* - - - - - 8,310

Uranite in a metallic state - - - - 6,440

Jungsten { of a grey colour - - - - { 5,800  
of a brown colour - - - - 6,028

{ of a brown colour - - - - 5,570  
in a metallic state † - - - 17,600

Molybdena in a metallic state, when saturated with water - - - - - 7,500

Sylvanite, or Tellurite, in a metallic state, twice fused - - - - - 6,343

Titanite - - - - - 4,180

\* This sp. gr. has been stated on the authority of Muschenbroek and Bergman; but Brisson states it at 5,7633.

† This specific gravity rests upon the authority of Elhuyart. It may possibly be a mistake. See Kirwan's Mineralogy, second edit. vol. 2, p. 308.

## Of the Specific Gravities of Bodies. 99

	Spec. Grav.
<b>Shorl</b> - - - - - - - - - {	2,920 3,212
<b>Shorlite</b> - - - - - - - - - {	3,530
<b>Tourmalin</b> - - - - - - - - - {	3,050 3,155
<b>Edelite, or Siliceous Zeolite</b> - - - - - {	2,515
<b>Lapis lazuli</b> - - - - - - - - - {	2,760 2,945
<b>Chrysoprasium</b> - - - - - - - - - {	2,489
<b>Opal</b> - - - - - - - - - {	1,700 2,118
<b>Hyalite or Lava Glass</b> - - - - - - - - - {	2,110
<b>Calcedony</b> - - - - - - - - - {	2,600 2,665
<b>Cornelian</b> - - - - - - - - - {	2,597 2,630
<b>Cat's Eye</b> - - - - - - - - - {	2,560 2,660
<b>Flint</b> - - - - - - - - - {	2,580 2,630
<b>Hornstone</b> - - - - - - - - - {	2,530 2,653
<b>Jasper</b> - - - - - - - - - {	2,500 2,820
<b>Egyptian pebble</b> - - - - - - - - - {	2,564
<b>Sinople</b> - - - - - - - - - {	2,691
<b>Heliotropium</b> - - - - - - - - - {	2,620 2,700
	<b>Woodstone</b>

*Of the Specific Gravities of Bodies.*

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	Spec. Grav.
Woodstone - - - - - - - - - -	{ 2,045 2,675
Felspar - - - - - - - - - -	{ 2,437 2,600
Labradore stone - - - - - - - - - -	{ 2,670 2,692
Agates - - - - - - - - - -	{ 2,580 2,666
Strontian earth - - - - - - - - - -	{ 3,400 3,644
Corundum stone, or adamantine spar - -	{ 3,876 4,166
Granites - - - - - - - - - -	{ 2,538 2,956
Chalk - - - - - - - - - -	{ 2,315 2,657
Arenaceous limestone - - - - - - - - - -	2,742
Compact limestone - - - - - - - - - -	{ 1,386 2,720
Foliated limestone - - - - - - - - - -	{ 2,710 2,837
Common spar - - - - - - - - - -	{ 2,693 2,778
Marbles - - - - - - - - - -	2,700
Gypsum - - - - - - - - - -	{ 2,167 2,311
Aerated barytes - - - - - - - - - -	{ 4,300 4,338

	Spec. Grav.
Baroselenite - - - - - - - -	{ 4,400 4,365
Lapis hepaticus - - - - - - - -	2,666
Talk, common, or Venetian - - - -	{ 2,700 2,800
Indurated steatites	{ before it has absorbed any water - - - - - 2,583 after having imbibed water - - - - - 2,632
Basalt from the Giant's Causeway - - - -	2,864
Pumice-stone - - - - - - - -	0,914
Oriental pearls - - - - - - - -	2,683
Diamond	{ oriental colourless - - - - - 3,521 oriental rose-coloured - - - - - 3,531 oriental orange-coloured - - - - - 3,550 oriental green-coloured - - - - - 3,523 oriental blue-coloured - - - - - 3,525 Brazilian - - - - - - - - 3,444
Asphaltum	{ cohesive - - - - - - - - { 1,450 compact - - - - - - - - { 1,070 1,165
Mineral tallow - - - - - - - -	0,770
Native mineral carbon, or pit-coal - -	{ 1,400 1,550
Plumbago - - - - - - - -	{ 1,987 2,089
Sulphur	{ native - - - - - - - - - - - - 2,033 fused - - - - - - - - - - - - 1,990
	Amber

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		Spec. Grav.
<b>Amber</b>	- - - - -	<b>{ 1,078</b> <b>{ 1,080</b>
<b>Glass</b>	white flint crown common plate yellow plate white, or crystal, of France St. Gobin's	about 3,300 about 2,520 about 2,760 2,520 2,892 2,488
<b>Porcelain</b>	Chima Seves from Saxony	2,384 2,145 2,493
<b>Copal</b>	transparent of Madagascar and China	1,045 1,061
<b>Ambergris</b>	- - - - -	<b>{ 0,780</b> <b>{ 0,926</b>
<b>Common rosin</b>	- - - - -	1,072
<b>Sandarac</b>	- - - - -	1,092
<b>Mastic</b>	- - - - -	1,074
<b>Storax</b>	- - - - -	1,109
<b>Elemi</b>	- - - - -	1,018
<b>Labdanum</b>	- - - - -	1,186
<b>Resin or gum of guaiac</b>	- - - - -	1,228
<b>Resin of jalap</b>	- - - - -	1,218
<b>Dragon's blood</b>	- - - - -	1,204
<b>Gum lac</b>	- - - - -	1,139
<b>Elastic gum, or <i>Caoutchouc</i>, commonly called India rubber</b>	- - - - -	0,933
<b>Camphor</b>	- - - - -	0,988
<b>Gum ammoniac</b>	- - - - -	1,207
<b>Myrrh</b>	- - - - -	1,360
	G 2	Gamboge

	Spec. Grav.
Gamboge -	1,221
Scammony -	about 1,235
Affafœtida -	1,327
Sarcocolla -	1,268
Gum arabic -	1,452
Gum tragacanth -	1,316
Inspissated juice of liquorice -	1,722
Opium -	1,336
Indigo -	0,769
Arnotto -	0,595
Yellow, or bees, wax -	0,965
White wax -	0,968
Dry ivory -	1,825
Spermaceti -	0,943
Honey -	1,450
Fat of beef, veal, mutton, &c. -	{ 0,923 0,948
Heart of oak, 60 years old -	1,170
Cork -	0,240
Trunk of elm -	0,671
Trunk of ash -	0,845
Beech wood -	0,852
Alder wood -	0,800
Maple wood -	0,755
Walnut wood -	0,671
Willow -	0,585
Fir wood -	{ 0,498 0,550
Poplar wood -	0,383
White Spanish poplar wood -	0,529
Apple	

*Of the Specific Gravities of Bodies.* 85

	Spec. Grav.
Apple tree	- 0,661
Quince tree	- 0,793
Medlar tree	- 0,944
Plumb tree	- 0,705
Olive tree.	- 0,927
Cherry-tree	- 0,715
Filbert tree	- 0,600
French box wood	- 0,912
Dutch box wood	- 1,328
Dutch yew tree	- 0,788
Spanish yew tree	- 0,807
Spanish cypress wood	- 0,644
American cedar tree	- 0,560
Pomegranate tree	- 1,354
Spanish mulberry tree	- 0,897
Lignum vitæ	- 1,333
Orange tree	- 0,705
Red Brazil wood	- 1,031
Logwood	- 0,913
Sassafras	- 0,482
Peruvian bark	- 0,784

Distilled Water, or Rain Water, at the following  
Degrees of Temperature, Fahren. Therm.

Heat.	Spec. Grav.	Heat.	Spec. Grav.
30	1,00074	58	1,00016
31	1,00078	59	1,00008
32	1,00082	60	1,00000
33	1,00085	61	0,99991
34	1,00088	62	0,99981
35	1,00090	63	0,99971
36	1,00092	64	0,99961
37	1,00093	65	0,99950
38	1,00094	66	0,99939
39	1,00094	67	0,99928
40	1,00094	68	0,99917
41	1,00093	69	0,99906
42	1,00092	70	0,99894
43	1,00090	71	0,99882
44	1,00088	72	0,99869
45	1,00086	73	0,99856
46	1,00083	74	0,99843
47	1,00080	75	0,99830
48	1,00076	76	0,99816
49	1,00072	77	0,99802
50	1,00068	78	0,99788
51	1,00063	79	0,99774
52	1,00057	80	0,99759
53	1,00051	85	0,99681
54	1,00045	90	0,99598
55	1,00038	95	0,99502
56	1,00031	100	0,99402
57	1,00024		*

\* Phil. Trans. vol. for 1792; Table II. p. 428; and  
vol. for 1794, p. 382.

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	Spec. Grav.
Sea water*	1,026
Water of the Dead Sea	1,240
Naphtha	0,847
Petrol	0,878
Sulphuric, or vitriolic, acid	1,841
Nitric acid	1,272
Muriatic acid	1,194
Red acetous acid	1,025
White acetous acid	1,014
Distilled acetous acid	1,010
Acetic acid	1,063
Solution of caustic ammonia, or fluid volatile alkali	0,897
Spirit, or volatile oil, of turpentine	0,870
Liquid turpentine	0,991
Volatile oil of lavender	0,894
Volatile oil of cloves	1,036
Volatile oil of cinnamon	1,044
Oil of olives	0,915
Oil of sweet almonds	0,917
Lintseed oil	0,940
Oil of poppy-seed	0,929
Whale oil	0,923
Woman's milk	1,020
Mare's milk	1,035
Aff's milk	1,036

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\* Is said to be heavier in the torrid zone, and far from the land.

	Spec. Grav.
Goat's milk - - - - -	1,034
Ewe's milk - - - - -	1,041
Cow's milk - - - - -	1,033
Cow's whey - - - - -	1,019
Human urine - - - - -	$\left\{ \begin{array}{l} 1,015 \\ 1,026 \end{array} \right.$
Human blood - - - - -	1,054
Craßamentum of human blood - - -	1,126
Alcohol, or pure spirituous liquor* - -	0,798
	Spirit

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\* The rectification of spirits (whether from wine, or rum, or malt-liquor, for it seems to be all the same thing) has been carried to a very great degree of perfection, by means of repeated slow distillations, together with the addition of alkaline salts, which have a very great power of absorbing the aqueous part of the liquor. The lightest spirit, which I find recorded, was used in France, by Chaussier, the specific gravity of which is stated at 0,798. See l'Encyclopédie Méthodique, art. *Alcohol*. In England it has been obtained, not without extraordinary care and attention, of the specific gravity 0,813. Phil. Trans. vol. for 1790, p. 324. But with moderate attention it may be constantly obtained of the sp. gr. 0,82514, and of this quality was the spirit which was used by Mr. Gilpin in his experiments for the construction of his very accurate Tables, wherein, for conveniency's sake, the trifling fraction c,00014 was omitted (see the Phil. Trans. for the year 1790, article XVIII; for the year 1792, art. XXII; and for the year 1794, art. XX.); from which the above specific gravities of water, of spirit, and of the mixtures of water and spirit, have been extracted.

The

*Of the Specific Gravities of Bodies.* 89

	Spec. Grav.
Spirit used for the Tables which are inserted in the Phil. Trans. for 1794 - }	0,825
Proof-spirit, according to the English Exercise Laws*	0,916

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Specific Gravities, at different Temperatures, of Spirit, whose Specific Gravity at  $60^{\circ}$  is 0,825.

Heat.	Spec. Grav.
$30^{\circ}$	0,83896
$35^{\circ}$	0,83672
$40^{\circ}$	0,83455
$45^{\circ}$	0,83214
$50^{\circ}$	0,82977
$55^{\circ}$	0,82736

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The last-mentioned gentleman having procured a specimen of spirit of superior levity, its specific gravity being 0,814196 at  $60^{\circ}$  of temperature, endeavoured to ascertain what addition of water it might require in order to equal his standard spirit; and upon trial found that when 1000 grains of it were mixed with 45 grains of water, the specific gravity of the compound was 0,825153, which may be considered as exactly equal to that of his standard spirit. Phil. Trans. for 1790, p. 340.

\* From the best interpretation of the existing Acts of Parliament, it seems that the specific gravity of what is called *proof-spirit*, is 0,916; and that it consists of 100 parts of rectified spirit of the specific gravity 0,825, and 62 parts of water by measure, or 75 by weight; the whole at  $60^{\circ}$  of heat. (Dr. Blagden's Report, Phil. Trans. for 1790, p. 339.)

Heat.

## 90 Of the Specific Gravities of Bodies.

Heat.		Spec. Grav.
60°	- - - - -	0,82500
65°	- - - - -	0,82262
70°	- - - - -	0,82023
75°	- - - - -	0,81780
80°	- - - - -	0,81530
85°	- - - - -	0,81283
90°	- - - - -	0,81039
95°	- - - - -	0,80788
100°	- - - - -	0,80543

## Real Specific Gravities of Mixtures of Spirit (of the above-mentioned Quality) and Distilled Water, at different Temperatures.\*

Heat.	100 grains of spirit to 5 grains of water.	100 grains of spirit to 10 grains of water.	100 grains of spirit to 15 grains of water,	100 grains of spirit to 20 grains of water.
30°.	0,84995	0,85957	0,86825	0,87585
35	0,84769	0,85729	0,86587	0,87357
40	0,84539	0,85507	0,86361	0,87134
45	0,84310	0,85277	0,86131	0,86907
50	0,84076	0,85042	0,85902	0,86676
55	0,83834	0,84802	0,85664	0,86441
60	0,83599	0,84568	0,85430	0,86208
65	0,83362	0,84334	0,85193	0,85976
70	0,83124	0,84092	0,84951	0,85736
75	0,82878	0,83851	0,84710	0,85493
80	0,82631	0,83603	0,84467	0,85248
85	0,82386	0,83355	0,84221	0,85006
90	0,82142	0,83111	0,83977	0,84762
95	0,81888	0,82860	0,83724	0,84511
100	0,81643	0,82618	0,83478	0,84262

\* By *real specific gravities*, are meant the specific gravities found by actual trial, and not those which might have been computed from the quantities of the ingredients. The latter do not agree with the former, on account of the incorporation or loss of bulk which takes place. See page 51.

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Heat.	100 grains of spirit to 25 grains of water.	100 grains of spirit to 30 grains of water.	100 grains of spirit to 35 grains of water.	100 grains of spirit to 40 grains of water.
30°.	0,88282	0,88921	0,89511	0,90054
35	0,88059	0,88701	0,89294	0,89839
40	0,87838	0,88481	0,89073	0,89617
45	0,87613	0,88255	0,88849	0,89396
50	0,87384	0,88030	0,88625	0,89174
55	0,87150	0,87796	0,88393	0,88945
60	0,86918	0,87568	0,88169	0,88720
65	0,86686	0,87337	0,87938	0,88490
70	0,86451	0,87105	0,87705	0,88254
75	0,86212	0,86864	0,87466	0,88018
80	0,85966	0,86623	0,87228	0,87776
85	0,85723	0,86380	0,86984	0,87541
90	0,85483	0,86139	0,86743	0,87302
95	0,85232	0,85896	0,86499	0,87060
100	0,84984	0,85646	0,86254	0,86813

Heat.	100 grains of spirit to 45 grains of water.	100 grains of spirit to 50 grains of water.	100 grains of spirit to 55 grains of water.	100 grains of spirit to 60 grains of water.
30°.	0,90558	0,91023	0,91449	0,91847
35	0,90345	0,90811	0,91241	0,91640
40	0,90127	0,90596	0,91026	0,91428
45	0,89909	0,90380	0,90812	0,91211
50	0,89684	0,90160	0,90596	0,90997
55	0,89458	0,89933	0,90367	0,90768
60	0,89232	0,89707	0,90144	0,90549
65	0,89006	0,89479	0,89920	0,90328
70	0,88773	0,89252	0,89635	0,90104
75	0,88538	0,89018	0,89464	0,89872
80	0,88301	0,88781	0,89225	0,89639
85	0,88067	0,88551	0,88998	0,89409
90	0,87827	0,88312	0,88758	0,89173
95	0,87586	0,88069	0,88521	0,88937
100	0,87340	0,87824	0,88271	0,88691

Heat.

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Heat.	100 grains of spirit to 65 grains of water.	100 grains of spirit to 70 grains of water.	100 grains of spirit to 75 grains of water.	100 grains of spirit to 80 grains of water.
30°	0,92217	0,92563	0,92889	0,93191
35	0,92009	0,92355	0,92680	0,92986
40	0,91799	0,92151	0,92476	0,92783
45	0,91584	0,91937	0,92264	0,92570
50	0,91370	0,91723	0,92050	0,92358
55	0,91144	0,91502	0,91837	0,92145
60	0,90927	0,91287	0,91622	0,91933
65	0,90707	0,91066	0,91400	0,91715
70	0,90484	0,90847	0,91181	0,91493
75	0,90252	0,90617	0,90952	0,91270
80	0,90021	0,90385	0,90723	0,91042
85	0,89793	0,90157	0,90496	0,90818
90	0,89558	0,89925	0,90270	0,90590
95	0,89322	0,89688	0,90037	0,90358
100	0,89082	0,89453	0,89798	0,90123

Heat.	100 grains of spirit to 85 grains of water.	100 grains of spirit to 90 grains of water.	100 grains of spirit to 95 grains of water.	100 grains of spirit to 100 grains of water.
30°	0,93474	0,93741	0,93991	0,94222
35	0,93274	0,93541	0,93790	0,94025
40	0,93072	0,93341	0,93592	0,93827
45	0,92859	0,93131	0,93382	0,93621
50	0,92647	0,92919	0,93177	0,93419
55	0,92436	0,92707	0,92963	0,93208
60	0,92225	0,92499	0,92758	0,93002
65	0,92010	0,92283	0,92546	0,92794
70	0,91793	0,92069	0,92333	0,92580
75	0,91569	0,91849	0,92111	0,92364
80	0,91340	0,91622	0,91891	0,92142
85	0,91119	0,91403	0,91670	0,91923
90	0,90891	0,91177	0,91446	0,91705
95	0,90662	0,90949	0,91221	0,91481
100	0,90428	0,90718	0,90992	0,91252

Heat.

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Heat.	95 grains of spirit to 100 grains of water.	90 grains of spirit to 100 grains of water.	85 grains of spirit to 100 grains of water.	80 grains of spirit to 100 grains of water.
30°	0.94447	0.94675	0.94920	0.95173
35	0.94249	0.94484	0.94734	0.94988
40	0.94058	0.94295	0.94547	0.94802
45	0.93860	0.94096	0.94348	0.94605
50	0.93658	0.93897	0.94149	0.94414
55	0.93452	0.93696	0.93948	0.94213
60	0.93247	0.93493	0.93749	0.94018
65	0.93040	0.93285	0.93546	0.93822
70	0.92828	0.93076	0.93337	0.93616
75	0.92613	0.92865	0.93132	0.93413
80	0.92393	0.92646	0.92917	0.93201
85	0.92179	0.92432	0.92700	0.92989
90	0.91962	0.92220	0.92491	0.92779
95	0.91740	0.91998	0.92272	0.92562
100	0.91513	0.91769	0.92047	0.92346

Heat.	75 grains of spirit to 100 grains of water.	70 grains of spirit to 100 grains of water.	65 grains of spirit to 100 grains of water.	60 grains of spirit to 100 grains of water.
30°	0.95429	0.95681	0.95941	0.96209
35	0.95246	0.95502	0.95772	0.96048
40	0.95060	0.95328	0.95602	0.95879
45	0.94871	0.95143	0.95423	0.95705
50	0.94683	0.94958	0.95243	0.95534
55	0.94486	0.94767	0.95057	0.95357
60	0.94296	0.94579	0.94876	0.95181
65	0.94099	0.94388	0.94689	0.95000
70	0.93898	0.94193	0.94500	0.94813
75	0.93695	0.93989	0.94301	0.94623
80	0.93488	0.93785	0.94102	0.94431
85	0.93282	0.93582	0.93902	0.94236
90	0.93075	0.93381	0.93703	0.94042
95	0.92858	0.93170	0.93497	0.93839
100	0.92646	0.92957	0.93293	0.93638

Heat.

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Heat.	55 grains of spirit to 100 grains of water.	50 grains of spirit to 100 grains of water.	45 grains of spirit to 100 grains of water.	40 grains of spirit to 100 grains of water.
30°	0,96470	0,96719	0,96967	0,97200
35	0,96315	0,96579	0,96840	0,97086
40	0,96159	0,96434	0,96706	0,96967
45	0,95993	0,96280	0,96563	0,96840
50	0,95831	0,96126	0,96420	0,96708
55	0,95662	0,95966	0,96272	0,96575
60	0,95493	0,95804	0,96122	0,96437
65	0,95318	0,95635	0,95962	0,96288
70	0,95139	0,95469	0,95802	0,96143
75	0,94957	0,95292	0,95638	0,95987
80	0,94768	0,95111	0,95467	0,95826
85	0,94579	0,94932	0,95297	0,95667
90	0,94389	0,94748	0,95123	0,95502
95	0,94196	0,94563	0,94944	0,95328
100	0,93999	0,94368	0,94759	0,95152

Heat.	35 grains of spirit to 100 grains of water.	30 grains of spirit to 100 grains of water.	25 grains of spirit to 100 grains of water.	20 grains of spirit to 100 grains of water.
30°	0,97418	0,97635	0,97860	0,98108
35	0,97319	0,97556	0,97801	0,98076
40	0,97220	0,97472	0,97737	0,98033
45	0,97110	0,97384	0,97666	0,97980
50	0,96995	0,97284	0,97589	0,97920
55	0,96877	0,97181	0,97500	0,97847
60	0,96752	0,97074	0,97409	0,97771
65	0,96620	0,96959	0,97309	0,97688
70	0,96484	0,96836	0,97203	0,97596
75	0,96344	0,96708	0,97086	0,97495
80	0,96192	0,96568	0,96963	0,97385
85	0,96046	0,96437	0,96843	0,97271
90	0,95899	0,96293	0,96711	0,97153
95	0,95727	0,96139	0,96568	0,97025
100	0,95556	0,95983	0,96424	0,96895

Heat.

Heat.	15 grains of spirit to 100 grains of water.	10 grains of spirit to 100 grains of water.	5 grains of spirit to 100 grains of water.
30°	0,98412	0,9804	0,99334
35	0,98397	0,98804	0,99344
40	0,98373	0,98795	0,99345
45	0,98338	0,98774	0,99338
50	0,98293	0,98745	0,99316
55	0,98239	0,98702	0,99284
60	0,98176	0,98654	0,99244
65	0,98106	0,98594	0,99194
70	0,98028	0,98527	0,99134
75	0,97943	0,98454	0,99066
80	0,97845	0,98367	0,98991
85	0,97744	0,98281	0,98912
90	0,97637	0,98185	0,98824
95	0,97523	0,98082	0,98729
100	0,97401	0,97969	0,98625

Sulphuric, or vitriolic, ether - - - 0,7396

Nitric ether - - - - - 0,9088

Muriatic ether - - - - - 0,7296

Acetic ether - - - - - 0,8664

Common, or atmospherical, air,\* the mercury in the barometer being 29,75 <sup>1<sup>a</sup>.</sup> high, { at 0° of heat 0,001393  
at 32° of heat 0,001299  
at 60° of heat 0,001220  
at 212° of heat 0,000938

Azotic

\* The specific gravity of common air is not constantly the same. It increases when the mercury rises in the barometer, and vice versa. Air is also expanded by heat, and is

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Azotic gas*	- barometer at 29,75 <sup>in.</sup>	0,001145
Oxygen gas*	- barometer at 29,75 <sup>in.</sup>	0,001305
Hydrogen gas*	- barometer at 29,75 <sup>in.</sup>	0,000091
Carbonic acid gas*	barometer at 29,75 <sup>in.</sup>	0,001682
Nitrous gas*	- barometer at 29,75 <sup>in.</sup>	0,001411
Ammoniacal gas*	barometer at 29,75 <sup>in.</sup>	0,000706

Besides shewing the comparative gravities of bodies, which are to be seen by bare inspection, the great use of a table of specific gravities is for ascertaining the real weights of bodies, and that without actually weighing them, when their dimensions are known, according to what has been already explained in page 43. But for this purpose it is necessary to know the real weight of a determi-

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is contracted by cold, though not regularly; the greatest expansion taking place between the degrees 52° and 72° of Fahrenheit's thermometer, and the least at about 212°. But the expansion for the same degrees of heat also varies according to the quantity of moisture in the air, and to the altitude of the mercury in the barometer. When this altitude is 29,75 and the air is in a mean state of moisture, it then receives an addition of 0,484 to its bulk by the heat of 212°; viz. a given measure of air at 0° becomes 1,484 measure at 212°, in which case the mean rate of expansion for each degree is  $\left( \frac{0,484}{212} = \right) 0,002283$ .

\* Those gasses, or artificial airs, are, besides the influence of pressure and heat, more fluctuating in their specific gravities. The above statements must be understood of their purest states.

nate

nate bulk of one of the substances that are mentioned in the table. Now since water has been assumed as the standard of comparison for the specific gravities of all other bodies, it will be more convenient to know the real weight of a certain quantity of water, viz. a cubic inch, or a cubic foot of it, than of any other body.

Though at first sight it may appear easy to determine the real weight of a certain bulk of water, yet the reader may rest assured, that this determination is attended with very great difficulties, which arise from the imperfections of the balance, of the weights, of the measures which are employed for measuring the bulk, &c.— From the most accurate experiments, performed with the best instruments, and with all the precautions which the present state of philosophical knowledge can suggest, it has been ascertained that a cubic inch of distilled water at the temperature of  $60^{\circ}$  weighs 252,576 grains troy; 5760 of which grains are equal to one pound troy.\*

The

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\* This weight has been calculated for the temperature of  $60^{\circ}$ , from the statement of Sir George Shuckburg Evelyn's elaborate paper in the Phil. Trans. for the year 1798; where, after the recital of his numerous experiments, this author expresses himself thus — “ In conclusion it appears “ then that the difference of the lengths of two pendulums, “ such as Mr. Whitehurst used, vibrating 42 and 84 times “ in a minute of mean time, in the latitude of London, at

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The general rule for determining the real weight of any substance which is mentioned in the preceding table, when its bulk is known, and is expressed in cubical inches, or by any other dimension which may be reduced into inches, is as follows. Multiply the weight of a cubic inch of water by the number of cubic inches which expresses the bulk of the body in question, and multiply the product by the specific gravity of the body in question. The last product expresses the real weight of the body.

Thus if it be proposed to determine the weight of 10 cubic inches of carbonic acid gas, which is the last substance but two in the table, and whose specific gravity is 0,001682 ; multiply the weight of a cubic inch of water by ten, and the product will be 2525,76 ; then multiply this product by 0,001682, and the product 4,2483283, will express the weight in grains of ten cubic inches of carbonic acid gas, viz.  $4\frac{1}{4}$  grains nearly, at the temperature of  $60^{\circ}$ , and when the barometer stands at 29,75 inches.

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" 113 feet above the level of the sea, in the temperature of  
"  $60^{\circ}$ , and the barometer at 30 inches, is = 59,89358 in-  
" ches of the parliamentary standard; from whence all the  
" measures of superficies and capacity are deducible."

" That agreeably to the same scale of inches, a cubic  
" inch of pure distilled water, when the barometer is at  
" 29,74 inches, and thermometer at  $66^{\circ}$ , weighs 252,422  
" parliamentary grains; from whence all the other weights  
" may be derived."

## CHAPTER IV.

### OF THE ACTIONS OF NON-ELASTIC FLUIDS IN MOTION.

HITHERTO we have explained the equilibrium of fluids, or the properties of fluids in a quiescent state. It is now necessary to examine the laws which relate to the same when in motion.

Fluids, like solids, are possessed of the general properties of matter, such as have been stated and illustrated in the first part of this work; and amongst those general properties the *inertia*, and the *force of gravity* have been shewn to form the foundation of the doctrine of motion. It has been observed that in practical cases the theoretical laws of motion cannot be verified to a great degree of exactness, on account of the fluctuating resistance of the air, and of the friction between the various moving parts of contiguous bodies. But besides these, fluids are obstructed in their motions by the attraction, adhesion, or viscosity, amongst their own particles; by their adhesion or attraction to other bodies, and likewise by some other circumstances which have not yet been sufficiently investigated.

The extensive application of the subject, and the imperfect state of knowledge relatively to it,

suggest to persons of science the necessity of instituting a long and serious experimental investigation, which, in addition to the discoveries and experiments that have been already made by many able persons, would much contribute to the advancement of the theory, and would prove very beneficial to mankind in various respects, as in the construction of hydraulic machines, construction of ships, navigation, &c.

The only plan which we can at present adopt, is, to state in a compendious manner the principal propositions which relate to the motion of fluids; then to point out some of the deviations from the theoretical rules which experience has clearly shewn; and, lastly, to refer the inquisitive reader to the works of the best authors who have written professedly on the subject.

*Proposition. I. The forces of a fluid medium on a plane cutting the direction of its motion with different inclinations successively, are as the squares of the sines of those inclinations.*

Let IKCH, fig. 15. Plate X. represent a fluid, for instance, the water of a river moving from IK towards CH; and let GB represent the edge or section of a plain surface, situated in the water, perpendicular to the surface of the water, but inclined to the direction of its motion, so as to make an angle DBG with it, which is called *the angle of incidence, or of inclination.*

Draw

Draw the quadrant arch ABF, make AG perpendicular to the direction of the fluid, and from B drop BD perpendicular to AG. Then AG, or its equal GB is the radius, and GD is the sine of the angle of inclination DBG. Now we have to prove that the force of the moving fluid upon the plane is as the square of the sine DG; viz. that if, in the situation which is represented by the figure, the sine or line GD measure four feet, and the pressure of the water upon the plane be equivalent to  $21\frac{1}{2}$  pounds; then, when the plane is situated at another inclination GT, where the sine GS measures 3 feet, the pressure of the water upon the plane will be equivalent to 12 pounds; for the square of 4 is 16, the square of 3 is 9, and 16 is to 9 as  $21\frac{1}{2}$  is to 12. Also when the plane lies in the situation GF, which is in the direction of the motion of the fluid, then the pressure upon it vanishes, or becomes equal to nothing.

In order to prove this proposition it must be recollected, that, according to the laws of oblique impulses, the force is to the effect as radius is to the sine of inclination, (see chap. VIII. of Part I.). Therefore in the present case, if the same quantity of water fell upon the plane in the situation AG, as in the situation GB, the pressures upon the plane in those two situations would be as AG to GD. But it is evident that in the situation AG a greater quantity of the fluid falls upon the plane, than in the situation GB; for in the latter situation the part

ADBC of the stream does not meet the plane: hence it is farther evident that the quantities of water which fall upon the plane in those two situations, are as AG to GD, and those different quantities of fluid must press forward with forces proportionate to their quantities; viz. as AG to GD: but the pressures on the plane are, on account of the inclinations only, as AG to GD: therefore, in consequence of both these causes combined together, the pressures on the plane in the two situations are as AG multiplied by AG, to GD multiplied by GD; viz. as the square of AG (which is the radius, or sine of the perpendicular direction) to the square of the sine GD. And the same reasoning is evidently applicable to any other inclination of the plane.

It is also evident that the effect or pressure on the plane is the same, whether the plane stands still and the fluid moves, or the fluid is at rest and the plane is moved towards IK in a direction parallel to its original situation; viz. with the same inclination.

Now in this explanation we have omitted several interfering circumstances; we have not taken notice of the particles of water after they have touched the plane; for those particles, after that meeting, must go somewhere. They cannot return towards IK, for that would be prevented by the current of the fluid; yet they form some opposition or impediment to the current, and that opposition varies

varies according to the velocity of the current, and the inclination of the plane. The water therefore which falls upon the plane must flow over the edge of the plane at B, and in a direction which crosses the original direction of the stream, as is indicated by the figure; and it thus forms another impediment to the motion of the stream, which contributes to alter the law which is expressed in the proposition. The effect of this last sort of obstruction is subject to very great variations, which depend upon the distance of the bottom and sides of the vessel, or banks of the river, from the plane; upon the quality of the fluid; but, principally, upon the velocity of the stream; for when the stream moves with very great velocity, the water, which, after having struck the plane, flows over the edges of it, has no time to go quite behind the plane, but is pressed forward by the water that follows, and, instead of going behind the plane, it tends to carry away, by the adhesion or viscosity of its parts, the water which it already finds behind the plane, (see fig. 16, Plate X.): hence the pressure on the plane is increased considerably; because in that case, the plane, besides its being pressed on one side, is also supported less on the other side.

We have also omitted to take into the account the effect of friction, which arises from the adhesion of the water to the plain surface, and from the attraction amongst the particles of the water:

but those causes of obstruction cannot be easily subjected to calculation, since they depend upon other fluctuating causes; such as the nature, purity, and temperature of the fluid, the nature of the plane, and the velocity of the motion.— It is in consequence of this adhesion or friction, that the plane suffers some degree of pressure, even when it stands in the direction GF, viz. in the direction of the stream.

It therefore evidently appears, that the theory of the motion of fluids depends on some certain, and upon other fluctuating causes, which render the investigation of it extremely difficult and perplexing.

These remarks on the various causes which render the result of experiments different from the deductions of the theoretical propositions, are also applicable in a greater or less degree to the following positions:

*Proposition II. If the inclination of the plane, in the construction of the preceding proposition, remain the same, and the velocity of the fluid varies, then the pressure on the plane varies as the square of the velocity.*

Thus, if, when the water moves at the rate of 2 feet per second, the pressure on a certain fixed plane is equivalent to 10 pounds; then, when the water moves at the rate of 5 feet per second, the pressure will be equivalent to  $62\frac{1}{2}$  pounds; for the

square of 2 is 4, the square of 5 is 25, and 4 is to 25, as 10 pounds are to  $62\frac{1}{2}$  pounds.

If in equal times the same quantity of water struck the plane with different velocities, the pressures would be as the velocities; viz. a double velocity would produce a double effect, a treble velocity a treble effect; because the momentum is equal to the product of the quantity of matter by the velocity; and, according to this supposition, the quantity of water is the same. But it is evident that when the velocity is double, a double quantity of water will strike against the plane in an equal portion of time; hence the pressure is doubled on account of the velocity, and again doubled on account of the double quantity of water; so that upon the whole the pressure becomes as 2 multiplied by 2, or as the square of 2.—For the same reason, when the velocity of the water is trebled, the pressure is as three times 3, or as the square of 3; when the velocity is quadrupled, the pressure is as the square of four; and, in short, the pressure on the plane will be as the square of the velocity.

However, on account of the above-mentioned causes of obstruction, this increase of pressure, in proportion to the square of the velocity, is by no means very regular, nor will it proceed beyond a certain limit.

The result of this proposition is evidently the same, whether the plane be supposed to remain fixed

fixed and the fluid to move, or the fluid be supposed to be at rest and the plane to be carried through it with the same invariable inclination.

— The same thing must likewise be understood of heavy bodies descending in fluids.

*Proposition III. If planes of different dimensions move with like inclinations, but with different velocities, and in different fluids; the pressure upon each plane will be as the product which arises by multiplying the square of the velocity by the area of the plane, and by the density of the fluid belonging to that plane.*

For it is evident from the preceding Proposition that when the areas of the planes and the fluids are alike, the pressures are as the squares of the velocities; and it is also evident, that, if the surface of the plane be doubled, (which makes it equal to twice the original plane,) or trebled, (which makes it equal to thrice the original plane,) &c. the pressure, or its equal, the square of the velocity will likewise be doubled or trebled, &c. Also this doubled or trebled square of the velocity must be again multiplied by the density of the fluid; for a fluid which weighs twice, or three times, or any other number of times, as much as another fluid, must produce a double, or treble, or other proportionate, effect.

In practical cases of this sort the result of experiments has been found to differ considerably from the theoretical calculations, which difference is produced by the above-mentioned fluctuating causes.

Thus

Thus far we have considered the quantity of pressure which fluids in motion exert upon planes, or planes in motion receive from fluids at rest. The particulars relative to the effects which are produced by that pressure, may be easily suggested by the recollection of what has been already stated and explained in the first part, respecting the effects of direct and oblique impulses; yet it will be of use to assist that recollection, by briefly observing, that a body which receives an impression from a fluid, will be driven (or, which is the same thing, the body must be supported) in a direction which is either directly opposite, or differently inclined, according as the direction of the pressure is direct or inclined in a greater or less degree.

Thus let ABHI, fig. 1. Plate XI, represent a current of water from H to A; let D represent the upper edge of a body with a flat surface, lying perpendicularly into the water, and held by means of ropes at E. Now in this situation, the current will exert its full and direct force against the plane surface of the body; and if the ropes be let go at E, the body will be driven down by the current, without deviating one way or the other. But if the said body be situated in a direction oblique to the stream, as at F, and be held by means of ropes at G; the force of the current will drive it against the side of the river as at K, and a lesser power will be required at G to prevent the body being driven away with the stream. In this case the

force

force of the stream upon the body must be resolved into two forces, viz. LM and MF, the former of which is counteracted by the power at G, whilst the latter drives the body towards the bank of the river, (see chap. VIII. of Part I.). But if, when the body is at F, the ropes be let go at G, then the body will be driven down by the current, nor will it run towards the bank; for in this case the body, by moving with the water, will be at rest relatively to it, and of course it will not receive any impression from it.

It is in consequence of the same principle that the ship AB, fig. 2. Plate XI. is impelled in the direction from A towards C, by the wind which blows from W towards H, upon the oblique sails FG, DE. But in this case of a ship, it must be remarked, that besides the sails, the wind blows also upon the body of the ship, upon the ropes, masts, &c. which are not oblique to the direction of the wind; in consequence of which the vessel is partly impelled towards H; and, in fact, this will be found to move in the line DK, though the direction of the body of the vessel be always parallel to AB. The distance CK, viz. of the place in which the ship is actually found after a certain time, from that in which it ought to have been according to its original direction AB, is called the *lee-way*; and this lee-way is proportionately greater, the more the wind is inclined to the sails.

The same principle likewise explains the action of the rudder in turning the ship; for when the ship AC, fig. 3. Plate XI. is in motion from A towards C, if the rudder be situated in the direction AB, oblique to the keel, the water falling obliquely upon it, impels it towards E, and of course the head C of the ship will be turned towards D. But when the ship is becalmed, the setting of the rudder astern to the keel will have no power to turn the ship, because the ship being at rest with respect to the water, no impulse can take place. (1.)

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(1.) The method of estimating the force of the wind upon the sails of a ship, or of a windmill; also the force of the water upon the rudder of a ship in motion, or upon the gates of a lock, or sluice in a river, &c. is derived from Proposition H. of this chapter. But this force or pressure of the wind upon the sails of a windmill, must not be mistaken for that force which turns the axis of the mill; nor must the force of the water upon the rudder of a ship be mistaken for the force which actually compels the ship to turn; for the latter is only a part of the former, as will be shewn by what follows.

*The force of wind, which strikes upon the sail, to turn the axis of a windmill; or the force of the water which strikes against the rudder, to turn the ship, is as the product of the sine multiplied by the square of the sine of the inclination of the sail to the wind, or of the rudder to the direction of the water.*

Let AB, fig. 4. Plate XI. represent the axis of a windmill, and DC one of its sails, situated in the direction EC, inclined

It is in consequence of the effects which arise from the different obliquity of impulses, that bodies of the same weight and bulk, but of different shapes, will move through a fluid with more or less

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clined to the direction GC of the wind, which is parallel to the axis AB.

Through any point G in the line GC, draw a line GE perpendicular to CE, and through the point E, where GE meets CE, draw EF perpendicular to GC. Then GC is the radius, GE is the sine, and EC is the cosine of the angle GCE, viz. of the inclination of the sail to the wind. Therefore, by Proposition II. of this chapter, the force of the wind upon the sail, when this is placed directly opposite to it, is to the force of the wind upon the sail, when this is placed in the oblique direction EC to it, as  $\overline{GC}^2$  is to  $\overline{GE}^2$ . But the force in the direction GE is resolved into two forces, viz. EF and GF, the latter of which being parallel to the axis, cannot contribute to turn it round; but the force FE, being perpendicular thereto, is employed entirely in turning the axis or the sail round. Now the force  $GE : \text{force } EF :: GC : CE$ ; therefore  $EF = \frac{GE \times CE}{GC}$ .

Hence  $GE : EF :: GE : \frac{GE \times CE}{GC} :: \overline{GE}^2 : \frac{\overline{GE}^2 \times CE}{GC}$   
 $::$  (making the radius GC equal one, or unity)  $\overline{GE}^2 : \overline{GE}^2 \times EC =$  the cosine multiplied into the square of the sine of the angle of inclination GCE; which product, therefore, expresses that part of the force of the wind upon each sail of the windmill, which contributes to turn the axis of the mill round.

less freedom. Thus it has been calculated, that if a cylinder going in the direction of its axis, and a sphere of the same diameter, move in the same fluid with the same velocity, the resistance to the motion of the cylinder will be double to that of

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Since, when the sine of an angle increases, the cosine decreases, and *vice versa*; therefore there is a limit, at which the product of the cosine by the square of the sine is the greatest, or maximum. This limit, or this maximum, is easily ascertained by the method of fluxions, and is done in the following manner.

Making the radius = 1, and putting  $x$  for the cosine EC, we have, (Eucl. p. 47. B. I.)  $\overline{EG}^2 = 1 - xx$ ; which multiplied by the cosine  $x$ , becomes  $x - x^3 =$  to the force of the wind upon each sail, to turn the axis of the mill. Since the fluxion of a maximum is = 0; therefore, when  $x - x^3$  is a maximum, its fluxion  $\dot{x} - 3x^2\dot{x} = 0$ ; or  $\dot{x} = 3x^2\dot{x}$ , which divided by  $\dot{x}$ , becomes  $1 = 3x^2$ : hence  $x^2 = \frac{1}{3}$ ; and  $x = \sqrt{\frac{1}{3}}$ . Therefore, working by logarithms,  $x = \frac{0 - 0,47712125}{2} =$

$-0,23856062 = 9,76143938$ , which is the logarithmic cosine of  $54^\circ. 44'. 8''$ . Therefore the most advantageous situation of the sail with respect to the direction of the wind, or the situation in which the wind has the greatest power to turn the sail and the axis of the mill round, is when the direction of the sail makes an angle GCE of  $54^\circ. 44'. 8''$ , with the direction GC of the wind.

The same sort of demonstration is applicable to the power which the impression of the water on the rudder of a ship in motion, has to turn the ship.

In fig. 5. Plate XI. AD represents part of the ship, B its

of the globe; which principally arises from the former presenting its flat base to the fluid; whereas the latter presents a curve surface which receives the fluid obliquely. Bodies of the same bulk, but of other different shapes, have been likewise subjected

its rudder situated in the oblique position EC. The direction of the water is from G towards C, since the vessel moves in the contrary direction. Therefore the water strikes against the rudder at an angle of inclination GCE, which, since the keel of the ship is parallel to CG, is equal to the angle SEC, which the rudder makes with the keel.

From any point G, in the line CG, drop GE perpendicular to CE, and from E drop EF perpendicular to CG. Then CG is the radius, GE is the sine, and CE the cosine, of the inclination of the rudder to the keel, or to the direction of the water. Now the direct force of the water, is to its oblique force upon the rudder, as  $\overline{CG}^2$  is to  $\overline{GE}^2$ ; the latter of which being resolved into the two forces EF and GF, it is evident that EF is the only force which can contribute to turn the ship; for GF, being parallel to the keel, can have no power upon it. Then  $GE : EF :: GC : CE$ ;

$$\text{therefore } EF = \frac{GE \times CE}{GC}; \text{ hence } GE : EF :: GE :$$

$$\frac{GE \times CE}{GC} :: \overline{GC}^2 : \frac{\overline{GE}^2 \times CE}{GC} :: (\text{the radius being } \equiv 1.)$$

$\overline{GE}^2 : \overline{GE}^2 \times CE$ ; which is exactly the same result as was obtained above for the sail of the windmill; and of course it admits of the same maximum, viz. the action of the water against the rudder has the greatest power of turning the ship, when the direction EC of the rudder makes the angle CES with the keel; or, which is the same thing, when it

jected to calculation with respect to the resistance which they receive from moving fluids. The shape of a body which will move through a fluid with the greatest freedom possible, has also been calculated ; but the results of actual experiments have been found to differ considerably from the theoretical determinations ; nor can we at present form any rules sufficient to ascertain those differences, since they depend upon a variety of fluctuating, and not, as yet, fully ascertained causes. If the reader be desirous of examining the subject still farther, he may consult the works that are mentioned in the note \*.

makes the angle E C G with the direction of the water, of  $54^{\circ} 44' 8''$ .

For the same reasons such must likewise be the angles BED, ACD, fig. 6. Plate XI. which the gates of the lock C D E make with the sides of the canal A C B E, in order that they may sustain the greatest pressure they are capable of, from the water on the side A C D E B.

\* Archimedes *de insidentibus humido*. Mariotte on the motion of water and other fluids. Lamy *de l'équilibre des liqueurs*. Newton's *principia*. Gulielmini's *mensura aquarum fluentium*. Gravesand's *phil.* Musschenbroek's *phil.* Switzer's *hydrost.* Varignon's *dissert.* in the Mem. Acad. Scien. The works on fluids of Belidor, Desoguliers, Clare, Emerson, Bossu, D'Alambert, Buat, &c. De Prony's *Architect. Hydraulique*. The report of the committee of the Society for the Improvement of Naval Architecture. London 1794. Venturi's experimental enquiries on the lateral communication of motion in fluids. Phil. Tr. &c.

## CHAPTER V.

OF THE ATTRACTION OF COHESION, OR CAPILLARY  
ATTRACTION; AND OF THE ATTRACTION OF  
AGGREGATION.

**B**EFORE we proceed any farther in the enumeration of the phenomena which relate to the motion of fluids, it will be necessary to lay down the results of the principal experiments which have been made concerning the attraction of cohesion, as also of aggregation, and to explain them in the best manner we are able; for by this means the reader will in some measure be enabled to comprehend how far these attractions are concerned in the movements of fluids, and how it happens that the actual motions of fluids through pipes, channels, holes, &c. are considerably different from those which might be derived from the general theory of motion.

The attraction of aggregation, is that which takes place amongst the homogeneous particles of the same sort of substance; and the attraction of cohesion, is that which takes place between the particles of heterogeneous bodies. See the latter part of chap. I. and the beginning of chap. II. of the present part.—The principal facts which have been observed relatively to those attractions, are as follows.

I. *The particles of water attract each other.*

The globular form of the drops of rain; the running of two drops of water into each other, when they

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are laid so near as to touch, and a variety of other phenomena, render this attraction very manifest.

II. There is an attraction between water and glass, which is increased by cold, and diminished by heat; but is, *ceteris paribus*, proportionate to the quantity of the surface of contact.

If the breath from the mouth be thrown upon a glass plate, it will be found to adhere to it longer in cold, than in hot, weather.

If a drop of water be laid upon glass, it will preserve a convex surface on the side farthest from the glass, but on the nearest side it will adapt itself to the surface of the glass, and will adhere to it with a certain degree of force; but if the same drop be spread over the surface of the glass, it will then lose its convex surface, and will adhere to the glass with much greater force, as may be proved by endeavouring to shake it off in both cases. By the dispersion, the particles of water are placed much farther from each other, hence their mutual attraction is diminished; and on the other hand the attraction between the water and the glass is increased by having augmented the surface of contact.

In either of those cases the water is attracted by the glass on one side only. But if another piece of glass be placed facing the former, and in contact with the film of water, then the water will be attracted and retained with greater force; and if the water be encompassed on every side by glass, as if it be enclosed in a narrow glass tube, then the attrac-

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tion will be stronger still, because the quantity of contact in proportion to the quantity of water, is thereby considerably increased. By this means the attraction is rendered so very manifest, that the denomination of *capillary attraction* has been suggested by this more usual mode of trying such experiments; which is by means of tubes, whose bore is about as fine as a *hair*, which in Latin is called *capillus*:

Put some water in a glass vessel, as in fig. 7. Plate XI. and near the surface of the glass the water will be found to rise a little way, forming a curve, as at A and B.—The like effect will take place if you dip part of a piece of glass in water, as at C and D.—This effect may be explained in the following manner.

Let AB, fig. 8. Plate XI. represent a section of the surface of a piece of glass, having its lower part immersed in the water BC. Imagine this surface to be divided into a number of indefinitely small parts *a*, *b*, *c*, *d*, &c. Then the part *a*, next to the surface of the water BC, will raise a quantity of water proportionate to its attractive force; but this quantity of water is thereby brought nearer to the part *b* of the glass, and is therefore attracted by it, whilst another quantity of water takes its place next to *a*. Again, the first quantity of water being raised to *b*, is brought nearer to the part *c* of the glass, hence it is attracted by it, and is raised to the place *c*, whilst the quantity of water at *a* takes its place, and an-

other quantity of water comes to the place *a*, and so forth.

In consequence of this attraction, the water ought to form a film equally thick, or the quadrilateral figure *gbas*, on the surface of the glass. But it must be considered, that besides the attraction towards glass, the water is possessed of the attraction of aggregation; viz. of the attraction of its particles towards each other; in consequence of which, when the first quantity of water has been raised to the place *a*, another quantity of water *s* is kept suspended, in consequence of the attraction of water to water, between the water at *a*, and the water *BC*. When the glass has attracted the water to *b*, the part *s* will be enlarged into *tz*, because the two quantities of water, *a* and *b*, can keep suspended a greater portion of water, than the quantity *a* by itself. Thus the water will ascend along the surface of the glass, and will remain adhering thereto, in such quantity as to form a counterpoise to the attraction of the glass; viz. the pressure of the water thus raised, and the attraction between it and the water *BC*, are all together a counterpoise to the attraction of the glass.

The real ascent of the water, which in fig. 8. has been enlarged for the sake of illustration, when the glass is either flat, or not much bent, seldom exceeds one tenth of an inch. But this altitude is increased or diminished by a variety of circumstances; viz. by the temperature and purity of the water, by the quality of the glass, and mostly by the polish and cleanliness of its surface.

Place a glass bubble A (that is, an empty glass ball) fig. 16. Plate XI. in a glass vessel not quite full of water. This bubble will float on the surface of the water, and it will be found to run spontaneously towards the side of the vessel, as at B, to which it will adhere with a certain force; provided, however, the bubble, on being laid upon the water, be not situated too far from the sides of the vessel.

This effect is owing to the attraction of the elevated water on the side of the vessel, and that on the surface of the bubble. Thus the water at *i* is attracted both by the water at *s* and by the water at *d*, which tends to bring those three parcels of water together; and of course the glass bubble also, which adheres to the water *d*. And this attraction grows stronger and stronger in proportion as those points come nearer to one another.

It is for the same reason that if two glass bubbles be placed upon water, at no great distance from each other, they will run towards each other, and will adhere with a certain degree of force.

If the glass vessel be filled, so that the water may project above the edge of the vessel; and a glass bubble be then laid upon it, as in fig. 17. Plate XI. the bubble will be found to recede from the sides of the vessel. In this case the elevated water *a*, which is contiguous to the side A, is attracted less powerfully than the elevated water *b*, by the water of the vessel; for on account of the convexity at A, the

water

water between A and  $a$ , is not so near to the elevation  $a$ , as an equal surface  $bB$  of water on the other side of the bubble, is to the elevation  $b$ .

III. *The perpendicular rise of water in glass tubes is inversely as the diameter.*—If glass tubes opened at both ends, be immersed with their lower apertures in water, as in fig. 9. Plate XI. the water will instantly rise spontaneously into their cavities, and it has been found that it will rise higher in narrower than in larger tubes, by as much as the diameter of the larger tube exceeds that of the smaller; the altitude in a tube of one hundredth part of an inch. (viz. 0,01) in diameter, being about 5,3 inches. Therefore in a tube of 0,02 in diameter, the altitude of the water will be the half of 5,3, viz. 2,65 inches in diameter. Also in a tube, whose diameter is 0,1 of an inch (or ten times 0,01) the altitude of the water will be the tenth part of 5,3; viz. 0,53 of an inch; and so forth \*.

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\* Since the diameters of the tubes are inversely as the altitudes of the water within their cavities, if you call the diameters  $D$ ,  $d$ , and the altitudes of the water  $A$ ,  $a$ , it will be  $D : d :: a : A$ ; whence  $AD = ad$ ; that is, the product of the diameter by the altitude of the water is always the same, or the constant quantity 0,053 of an inch; for when the diameter is 0,01 of an inch, the water has been found to rise in it to the altitude of 5,3 inches; and  $5,3 \times 0,01$  is equal to 0,053.

Therefore,

glass, which is in contact with it; and of course is proportionate to that surface. But in estimating the quantity of that counterpoise, or of the pressure of the column of water, we must take, besides the quantity, the altitude also, into the account; because, *cæteris paribus*, fluids press in proportion to their perpendicular altitudes; and when the base varies, or in different cylindrical pillars, the pressure are as the products of the quantity of matter by the altitude of each pillar respectively. Therefore the pressure of the pillar of water in a glass tube, which is a counterpoise to the attraction of the glass, is the product of the quantity of water by the altitude, and in cylindrical tubes, this product is always proportional to the surface of glass in contact with the water \*. This may be rendered more intelligible by means of an example.

Let the inside diameter of a tube BC, fig. 12 Plate XI. be double that of the tube DF; then the pillar of water FE will be two inches high when the pillar AC is one inch high. Since the contents of cylinders of the same altitude are as the squares of their respective diameters, and their surfaces are

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\* It has been shewn in the preceding note, that the surface of the glass tube which is in contact with the pillar of water, is a constant quantity; therefore the product of the quantity of water by the altitude of the pillar, must likewise be a constant quantity; since it is as the above-mentioned surface.

simply as their diameters, it is easily calculated that if the quantity of water in the pillar EF weighs 2 grains, that of AC must weigh 4 grains, and likewise that the surface of glass in contact with the pillar of water EF, is equal to the surface of glass which is in contact with the pillar of water AC; whence at first sight it should seem that those equal surfaces ought to keep suspended equal quantities of water, whereas the quantity of water EF is the half of the quantity of water AC; but the pillar of water EF is as high again as the pillar AC; hence its pressure which is equal to the product of the quantity of water by the altitude (viz. 2 grains by 2 inches) is equal to the pressure of the column AC, viz. to the product of 4 grains by one inch,

The above-mentioned phenomena of the attraction of cohesion shew, that what has been mentioned in the preceding chapter concerning the rise of water to the same level in different pipes, which communicate together, is not strictly true. Indeed, when the pipes are larger than an inch in diameter, the difference of the altitudes becomes insensible. But with narrower pipes of different diameters, the water may be plainly perceived to stand higher in the smaller than in the larger pipes.

IV: If a tube consist of two cylinders, viz. of the narrow part EF, fig. 14. Pl. XI. whose diameter is equal to that of the tube AB, wherein the water would rise to the height AB; and of the larger part CD, whose diameter is equal

equal to that of the tube GH, wherein the water would rise to the height GH; and if this compound tube be placed with the narrow aperture in water, as at F the water will not rise in it bigger than the altitude GH, viz. to the same altitude to which it would rise if the tube were an uniform cylinder of the diameter of the large part.

Here it might be expected that the water would rise higher than DG; but it must be considered that though the product of the pillars of water EF by its altitude, is less than a just counterpoise to the attraction of the surface EF of the glass; yet the overplus of attraction of that surface, instead of assisting to support the water in CE, will operate in a contrary way; that is, if we reckon the attraction of the surface EF equal to 10, and if the pressure of the pillar of water in it, be equal to 8; then the two remaining parts of attractive power will tend to draw the water from the basin, as much as from the cavity DE, towards the surface EF; so that by the addition of the narrow tube EF, the attraction of the larger part DI is diminished; at the same time that the water in it is partially supported by what may be called its perforated base IE.

V. If a compound tube, consisting of a larger part LN, fig. 14. Plate XI. wherein the water would rise spontaneously to the altitude M. and of a narrower part OK, equal in diameter to the tube AB, wherein the water would rise to the height AB; be filled with water as high as K, and then be placed with the large aperture

aperture in water as at N, the whole quantity of water will remain suspended, filling the whole of the large tube and part of the narrow one. The same thing will also take place with a vessel of any shape, as P Q S, provided its upper part be drawn into a narrow cylinder, equal in diameter to the tube A B.

In those vessels the water is supported partly by the attraction of cohesion, and partly by the pressure of the atmosphere. But not having as yet treated of the pressure and other properties of the atmosphere, it will not be possible for the novice to understand at present the action of that pressure; I shall therefore subjoin the explanation of the above-mentioned phenomenon in the note, for the immediate perusal of those readers who are otherwise acquainted with the properties of the atmosphere, or of the novice, on a second perusal of this work\*.

## VI. Water

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\* That this phenomenon is occasioned in great measure by the pressure of the atmosphere, is evident from the following observations; first, because the water will not rise spontaneously into the vessels O N, P S, to the height K and P; and secondly, because if those vessels, full of water as high as P, K, together with the basin, be placed under the receiver of an air-pump, on exhausting the receiver of air (viz. on removing the pressure of the atmosphere), the water will descend in them, and will remain in them only as high as it would ascend spontaneously; whereas all the preceding phenomena of capillary attraction, or of attraction of cohesion,

VI. Water rises between contiguous glass plates and follows the same law as it does with tubes

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hesion, and likewise all the others which are related in this chapter, will answer as well in vacuo as in air; unless contrary be mentioned.

How the water comes to be supported in those vessels partly by the attraction and partly by the atmosphere, will be shewn by the following example and calculation:

A column of water of about 32 feet perpendicular altitude, is a counterpoise to a column of air of the altitude of the whole atmosphere. Therefore, if the perpendicular height of the water in the vessel PQS, be one foot, its pressure will be equal to the  $\frac{1}{32}$ <sup>d</sup> part of the pressure of the atmosphere; hence the atmosphere presses on the aperture of the tube P, with one  $\frac{1}{32}$ <sup>d</sup> part of its power; (since the pressure of the atmosphere at the aperture QS, which otherwise would exactly counteract the pressure at P, is diminished by the pressure of the water in the vessel PQS;) and unless air comes in at the aperture P, the water will not descend in the vessel. Now let us suppose that the diameter of the aperture P be 0,004 of an inch; for it must be of about that size when the perpendicular altitude PQ of the vessel is one foot. The pressure of the atmosphere upon a square inch has been found to be about equal to the weight of 16 pounds, or 224 ounces, or 98056 grains; but the area of the aperture P, whose diameter is 0,004 of an inch, is 0,0001256 of an inch; therefore, by the rule of proportion, we say, as one square inch is to the area 0,0000125, so is the pressure of the atmosphere upon a square inch (viz. 98056 grains) to the pressure of the atmosphere on the area 0,0001256. And multiplying 98056 by 0,0000125

namely, the altitudes are inversely as the distances of the plates.

If the glass plates be parallel to each other, and be placed with their lower edges in water, the water will rise between them, and will remain suspended at a certain height. This height is not so great as that of the water in a glass tube, whose diameter is equal to the distance between the two plates; and that for an obvious reason; namely, because in the

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we obtain the product 1,23158336, viz. little more than one grain, which is the entire pressure of the atmosphere on the surface of the water in the tube at P. But it has been shewn above, that the atmosphere presses upon that surface with only the  $\frac{1}{32}$ <sup>th</sup> part of its entire force; therefore we must divide 1,23158336 by 32, and the quotient 0,03848698, or  $\frac{1}{32}$ <sup>th</sup> of a grain nearly, is the real and actual pressure of the atmosphere on the surface of the water at P; and this trifling pressure will be easily allowed not to be sufficient to overcome the attraction between the water and the surface of the tube P: Hence the water remains suspended in the vessels PQS, or ON.

This explanation is corroborated by the following experiment.—Fill the vessel ON, or PQS, not entirely, but only up to the height T; which is done by lowering them in the water of the bason; and in that situation touch the aperture O, or P, with a wet finger, so as to introduce a little water into it. Then if the vessel be drawn up, leaving its lower aperture only in the water of the bason; the column of water TN, or TQ, will remain suspended in it, though there is no communication whatever between the water at T, and the water in the capillary aperture.

tube the water is surrounded by glass on every side; yet the proportion is the same, that is, in two or more pairs of glass plates, the altitudes of the water are inversely as the distances of the plates; and that for the same reason as in glass tubes. A C D F, and B C D E, fig. 11. Plate XI. represent two flat glass plates, placed so as to form a small angle A C B, and immersed with their lower edges in water. The water will be found to rise between them, and to remain suspended in the space E F C D E, the outer edge of which, E F C, being a curve called an *hyperbola*. One extremity of this curve rises as high as the upper part of the glass plates at C, and the other extremity reaches as far as the edges of the glasses contiguous to the water of the basin at F and E.

The water between those plates rises higher near the side C D, and lower at a distance from it. In short, at any distance from C D, as at *a b*, *c d*, *e f*, the water rises as high as it would rise between parallel plates, whose distance from each other equalled the distance between the plates of fig. 11. at any of those particular places. Therefore the altitudes of the water at different distances from C D, are inversely as the distances between the two plates at those places (1.)

A B C E,

(1.) In fig. 13. Plate XI. (which represents the same elevation of water which is represented in fig. 11.) any two or more

A B C E, fig. 10. Plate XI. are two flat glass plates, forming a small angle with each other, like those of the preceding figure; the lowermost of which is placed so as to form a small angle with the horizon, having the edge A B a little elevated. Those plates may be kept separate at E C, by the interposition of a bit of wax, or other small body.

If a drop of water be introduced between those plates at E C, so as to touch both plates, this drop will be seen to move spontaneously towards the upper part of the glass plates, as far as the edge A B.—It will ensure the success of the experiment, if the inner surfaces of the glasses be previously lamped with water.

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The altitudes of water, as  $a b$ , and  $c d$ , are inversely as the distances  $b t$ ,  $d i$ , between the two plates at those places;  
 $ab : cd :: di : bt ::$  (by the similarity of the triangles  $t, Ddi$ .)  $Dd : Db$ ; and this is the property of the non hyperbola, whose asymptotes are the edge C D of glasses, and the line DS, where the glass plate cuts the surface of the water in the vessel G.

is evident that the water must rise as high as the apex C whatever be the altitude of the plates, since near the edge C the glass plates come infinitely near to each other.

If the glass plates, instead of being flat, be bent more or less, the edge of the water which rises between them will be an hyperbola, but it will vary according to the curvature of the plates. See Ditton's Discourse on the Properties of Fluids.

degrees in different bodies. When a metal for instance is dissolved in *aqua fortis*, that effect is owing to the particles of the metal having a greater attraction for those of the *aqua fortis*, than for each other.

For the sake, however, of distinction and perspicuity, when the attraction between two bodies is not so powerful as to occasion a manifest change of nature in either of the bodies, it is called *attraction of cohesion*, and when it produces a change, it is then called *attraction of affinity*, or *specific attraction*.

We shall, therefore, treat of the attraction of affinity in other chapters of this work, and shall confine the present merely to the attractions of cohesion and aggregation.

The explanations of the phenomena, which have been already described concerning glass and water, are sufficient to illustrate, and to account for, those which may be observed between other fluids and glass, or between other fluids and other solids, allowing for the difference which arises from different attractive forces: yet, as quicksilver has a much stronger attraction of aggregation than cohesion to glass, it will be proper briefly to describe the principal experiments that have been made with those two substances; lest the novice, surprised at the peculiarity of the phenomena, should be induced to suppose that a repulsion exists between these substances.

If a small globule of quicksilver be laid upon clean paper, and a piece of glass be brought into contact with it; the mercury will adhere to it, and will be drawn away from the paper. If, whilst the small globule of quicksilver is thus adhering to the glass, a larger quantity of quicksilver be brought in contact with the small globule, the latter will immediately forsake the glass, and will incorporate with the other quicksilver; which shews the greater degree of attraction between the particles of mercury than between them and glass: hence it will be found impracticable to spread the quicksilver, like water, over the surface of glass. The small globule of quicksilver adheres to the glass with a little flat surface, which renders the shape of the mercury not perfectly globular: but this little derangement of shape must not be considered as incompatible with the strong attraction between the particles of the mercury; for though this attraction be greater than the attraction towards the glass, yet the latter must produce a proportionate effect; hence a small change of shape; whereas if water were used in lieu of quicksilver, the surface of contact would be much greater.

Place a pretty large drop of quicksilver upon clean paper, and let two pieces of glass touch it on opposite sides. On drawing the glasses gently from each other, the mercury will, in consequence of its adherence to the glasses, be drawn from a circular into an oblong, or oval, shape.

If quicksilver be put in a glass, or wooden, or earthen vessel of upwards of an inch in width, the surface of the quicksilver will be horizontal towards the middle, but convex towards the sides. This also is the case when a pretty large quantity of quicksilver is laid upon a table, or on a piece of paper, or other flat surface; the gravity of it then exceeding the attraction of cohesion.

If an iron ball (which will float upon quicksilver) be laid upon it, a depression of the quicksilver will be observed all round the ball, as in fig. 18. Plate XI. and the ball will run towards the side of the vessel, provided it be not situated too far from it. Also, if two such balls be placed upon quicksilver, but not very far asunder, they will run towards each other. The reason of which is, that where the cavities or depressions of the quicksilver are joined; that is, either between the ball and the side of the vessel, or between the two balls, there the pressure of the quicksilver upon the ball, or balls, is diminished by the attraction of the quicksilver below; and of course the balls are impelled that way by the superior pressure on the opposite sides.

If a small tube A B, fig. 19. Plate XI. open at both ends, be partly immersed in mercury, the mercury will be found to stand lower within the tube than in the vessel; and this depression has been found to be inversely as the diameters of the tubes.

Thus, if two tubes are immersed in quicksilver, and the diameter of one is double the diameter of the other; then the difference of perpendicular altitudes between the surface of the quicksilver in the latter tube and in the bason, will be double to the like difference with the former tube.

Quicksilver being an opaque body, it will be necessary to hold the tube A B near the side of the vessel, which is supposed to be of glass, in order that the depression of the quicksilver within the tube may be perceived.

The same thing takes place between parallel glass plates; viz. if they be immersed in quicksilver, that fluid metal will stand lower between them than in the rest of the vessel; and the depression is likewise inversely as the distances between the plates. If the plates be situated so as to form a small angle; then the quicksilver, rising less near the angular edge than at a distance from it, will form a curve\*.

If a glass plate be laid in an horizontal situation, with a largish drop of quicksilver near one edge of it, as in fig. 20. Plate XI. which represents a section of it, and another glass plate, A B, be laid so as to form a small angle with it, and at the same time to compress the drop of quicksilver; the latter will be found to move spontaneously towards O, viz. towards

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\* This curve is an hyperbola, whose asymptotes are the perpendicular edge or joining of the glasses, and the level of the mercury in the bason.

the aperture of the angle, in order to recover its nearly globular figure.

If a tube open at both ends, but having its lower end drawn out into a fine capillary aperture, be filled with quicksilver to the altitude of about an inch or two, no mercury will be found to run out of the lower aperture; but if this lower end be suffered to touch other mercury, or if, by breaking off part of the small end, the aperture be enlarged, then the quicksilver will readily run out.

Those phenomena with quicksilver are so evidently dependent on its having a much greater attraction of aggregation than of cohesion to glass; and they are so evidently similar, though in a contrary way, to those which take place between water and glass, that after the particular explanations which have been given of those with water, it is needless to dwell any longer upon those with quicksilver.

These attractions of cohesion and aggregation form a considerable impediment to the thorough investigation of the laws of motion with respect to fluids, as their influence is far from having been entirely ascertained. Even the laws of equilibrium are affected by them. Thus it frequently happens, that if two fluids of different specific gravities, like water and spirit of wine, be mixed together, they will afterwards remain mixed; whereas the lighter fluid ought to ascend and to float upon the heavier.

Thus also, if a small steel needle, clean and dry, be gently laid upon water, the needle, though specifically heavier than water, will be found to float upon

ix. This effect is owing to the attraction of the particles of water to each other, which the small weight of the needle is not sufficient to overcome. The weight of the needle depresses the particles of water which are directly under it, and these, by their adhesion to the contiguous particles, draw them also below the usual level; and thus a cavity of considerable breadth is formed all round the needle, which cavity may be easily perceived in a proper light.

This effect has been commonly attributed to a supposed repulsion between water and steel, which is not true; for though the particles of water attract one another with greater force than they do those of steel; yet there is a degree of attraction between them and steel, which is shewn by the adhesion of the drops of water to iron and to steel.

If any water happen to get over the floating needle in the abovementioned experiment, then the latter falls immediately to the bottom.

The different degrees of the attraction both of aggregation and of cohesion between the particles of the same substance, or of different substances, seem to form all the immense gradation from the most fluid to the most solid body, whether simple or compound. The states intermediate between those extremes, are expressed by the various names of fluid, clammy, soft, glutinous, tenacious, hard, brittle, rigid, &c. But as those names are incapable

pable of any precise definitions, their meanings are commonly used, and understood with considerable latitude. The state of a given body in this respect is ascertained, either by observing the weight or force which is required to disunite its parts ; or by comparing it with other bodies ; as when it is said, that a ruby is softer than a diamond, but harder than the hardest steel, because with it you may scratch the steel but not the diamond\*.

Various experiments have been instituted for the purpose of determining the force requisite to

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\* In the formation of several stony concretions ; in the crystallization of salts, after having been dissolved in water ; in the cooling of certain metals after fusion, &c. a regular arrangement of parts is generally observed ; the particles of bodies shewing a tendency to join in a particular way. It has likewise been observed, that in the formation of stony concretions, and in some other processes, the slower the operation is performed, the harder the bodies are, which result therefrom. Now all this has suggested the supposition that the particles of the same sort of matter have an attraction towards each other with certain ends, and a repulsion with the opposite parts. Hence, when they are placed in such a situation as may allow them to follow that natural inclination, viz. when they are rendered fluid by heat, or by solution in water, &c. then they adhere to each other with their friendly parts. Also when the operation proceeds slowly, then the particles have more time to arrange themselves properly, and consequently form a harder body, than when the operation proceeds more expeditiously. See Higgins on

disunite solids from contiguous fluids, to disunite solids from contiguous solids, and to break or to disunite the continuity of a given solid. But the circumstances of temperature, purity of the bodies, equality of size, surface, &c. render such experiments subject to a considerable uncertainty ; I shall, notwithstanding, subjoin some of the less equivocal results of such experiments. The properties of solids do not belong to this part of my work ; but those particulars, which relate to their hardness and tenacity, could not with propriety be inserted in any other part of these elements.

If from each of two leaden bullets a piece be cut off with a sharp knife, and if then the two bullets be pressed with their flat bright surfaces against each other, (giving them a little twist), they ill be found to adhere so firmly to each other, that sometimes the weight of 100 pounds will hardly be sufficient to separate them. When separated, a considerable degree of roughness will be found on their surfaces\*. The best way of performing this experiment is represented in fig. 21. Plate XI. which shews two

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\* The adhesion of the two bullets is certainly not owing to the pressure of the surrounding air ; for in the first place the atmospherical pressure is by no means so great as to produce that degree of adhesion between such small surfaces ; and, in the second place, the two bullets thus prepared are found to adhere about as firmly in vacuo as they do in air.

prepared bullets adhering to each other, and each having a ring or bit of string passing through a hole, so that one of the rings may be fastened to a nail, or other steady support, whilst the necessary weight may be suspended to the other ring. The flat and smooth surfaces of other metals, of glass, &c. do also cohere to each other with considerable force; but with such bodies as are not so pliable as lead, a certain artifice is required for the purpose; namely, the interposition of some fluid as water, oil, &c. or of some substance which may be applied in a fluid state, though it may afterwards coagulate and grow solid, as tallow, wax, or fluid metals.

Two brass polished flat surfaces, 2 inches in diameter, smeared over with grease, and put together in a pretty hot state, will, when cold, adhere to each other so firmly as to require nearly 600 pounds weight to separate them.

Every body knows how firmly two pieces of metal adhere to each other, when they are soldered together; that is, joined by the interposition of another metal in a fluid state.

It must be observed, however, that in these last experiments, where something is interposed between the two surfaces, the adhesion seems to take place, not between the surfaces of the two solids, so much as between each of those surfaces and the interposed substance; for, in the first place, it seems strange that two surfaces should have a greater attraction to each other

other when something is interposed, than otherwise; and secondly, it has been found that the degree of adhesion differs according as different substances, viz. oil, or water, or wax, grease, turpentine, &c. are interposed between the surfaces of the very same solids.

The adhesion in these experiments is partly attributed to the pressure of the atmosphere, because sometimes the adhering plates are separated in an exhausted receiver. But, on the other hand, it seems likely that the separation of some of them in the exhausted receiver is occasioned rather by the extrication of air from the substance which is interposed, than by the removal of the atmospherical pressure.

The tenacity or strength of different substances is measured by the force which is required to break them. In a temperate degree of heat, it has been found that wires of the following metals, drawn through the same hole, one tenth of an inch in diameter, and fastened with one end to a nail, whilst weights were suspended to the other, could not be broken by any force less than the annexed weights\*.

Lead	—	—	29 $\frac{1}{2}$	Pounds.
Tin	—	—	49 $\frac{1}{2}$	
Copper	—	—	299 $\frac{1}{2}$	
Brass	—	—	360	
Silver	—	—	370	
Iron	—	—	450	
Gold	—	—	500	

\* If the metals, instead of being formed into wire by being passed through a hole, be simply cast in the same mould successively, and be then broken by means of weights, their tenacity will be found somewhat different from the statements of the above table.

A considerable difference in the tenacity of metallic substances is occasioned by their purity, temperature, manner of forming them, &c. But with other substances, the fluctuation of their tenacity is much greater than with metals, as will appear from the following observations of Mr. Emerson.

" A piece of good oak, an inch square, and a yard long, supported at both ends, will bear it in the middle, for a very little time, about 33c pounds avoirdupoise; but will break with more than that weight. This is at a medium; for there are some pieces that will carry something more, and others not so much. But such a piece of wood should not, in practice, be trusted for any length of time with above a third or fourth part of that weight. For since this is the extreme weight which the best wood will bear, that of a worse sort must break with it. I have found by experience, that there is a great deal of difference in strength, in different pieces of the very same tree; some pieces I have found would not bear half the weight that others would do. The wood of the boughs and branches is far weaker than that of the body; the wood of the great limbs is stronger than that of the small ones; and the wood in the heart of a sound tree is strongest of all. I have also found by experience, that a piece of timber, which has borne a great weight for a small time, has broke with a far less weight, when laid upon it, for a far longer time. Wood is likewise weak

" weaker when it is green, and strongest when tho-  
" roughly dried, and should be two or three years  
" old at least. If wood happens to be fappy, it  
" will be weaker upon that account, and will like-  
" wise decay sooner. Knots in wood weaken it  
" very much, and this often causes it to break  
" where a knot is. Also when wood is cross  
" grained, as it often happens, in sawing, this will  
" weaken it more or less, according as it runs more  
" or less across the grain. And I have found by  
" experience, that tough wood cross the grain, such  
" as elm or ash, is seven, eight, or ten times weaker  
" than straight; and wood that easily splits, such as  
" fir, is 16, 18, or 20 times weaker. And for com-  
" mon use it is hardly possible to find wood, but it  
" must be subject to some of these things. Besides,  
" when timber lies long in a building, it is apt to  
" decay, or be worm-eaten, which must needs very  
" much impair its strength. From all which it  
" appears, that a large allowance ought to be made  
" for the strength of wood, when applied to any  
" use, especially where it is designed to continue  
" for a long time."

" The proportion of the strength of several sorts  
" of wood, and other bodies that I have tried, will  
" appear in the following table:

Box, yew, plum-tree, oak	—	—	11
Elm, ash	—	—	8 $\frac{1}{2}$
Walnut, thorn	—	—	7 $\frac{1}{2}$

Red fir, hollin, elder, plane, crab-tree, apple-tree	—	—	—	—	7
Beech, cherry-tree, hazle	—	—	—	—	6 $\frac{1}{2}$
Alder, asp, birch, white fir, willow or saugh	—	—	—	—	6
Iron	—	—	—	—	107
Brass	—	—	—	—	50
Bone	—	—	—	—	22
Lead	—	—	—	—	6 $\frac{1}{2}$
Fine free-stone	—	—	—	—	1

“ A cylindric rod of good clean fir, of an inch circumference, drawn in length, will bear at the extremity 400 pounds, and a spear of fir 2 inches diameter, will bear about seven tons ; but not more.”

“ A rod of good iron of an inch in circumference, will bear near 3 tons weight.”

“ A good hempen rope of an inch in circumference, will bear 1000 pounds at the extremity.”

“ All this supposes these bodies to be sound and good throughout ; but none of these should be put to bear more than a third or a fourth part of that weight, especially for any length of time.”\*

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\* Emerson's Princip. of Mechan<sup>s</sup>. sect. VIII.—See also Musschenbroek's *Introd. ad Philos. Nat. Caput XXI. De Cohesione, et Firmitate*, wherein a great many experiments are mentioned relative to the adhesion, strength, tenacity, &c. of various substances.

The word *strength* has often been indiscriminately used for expressing the tenacity, the brittleness, or the rigidity of bodies; but those qualities must be duly distinguished from each other, whenever any of them is to be used in mechanics, or in other circumstances. Thus glass may be broken incomparably easier than iron, and a glass rod can support a much smaller weight than what can be supported by an equal iron rod: yet iron may be scratched with glass, but the latter cannot be scratched with the former.

With respect to hardness, the metals may be placed in the following order, beginning with the hardest, and ending with the softest: iron, platina, copper, silver, gold, tin, and lead.

The same of the semi-metals, as far as it is known. Manganese, nickel, bismuth, tungsten, zinc, antimony, and arsenic.

With respect to the difference of elasticity, the metals seem to follow the same order as they do with respect to hardness; except that perhaps copper might be placed before platina.

The rigidity and the elasticity of metallic substances, are increased by a variety of means, the principal of which are hammering, pressing, cooling suddenly, and mixing some of them together in due proportions. And on the other hand, their rigidity and elasticity are diminished (except when they arise from mixture) principally by heating and cooling gradually.

Steel may be rendered harder than any other metallic substance. Thus if a piece of steel be heated

red hot, and in that state be plunged in oil, it will thereby become so hard, that a file will hardly scratch it ; and it will be rendered still harder, if instead of oil, the red hot steel be plunged in water ; but if cold mercury be used instead of either of those liquors, then the steel will be rendered so hard as to scratch glass nearly as well as a diamond.

The hardness of other natural solids, besides the metals, differs considerably, according to the state of purity and of various other circumstances. However, a useful gradation of the principal natural solids, with respect to hardness, is exhibited in the following list, which begins with the hardest and ends with the softest.

Diamond, from Ormos.	Sardonyx
Pink, bluish, or yellowish, diamond.	Amethyst
Cubic diamond.	Mineral, or rock crystal.
Pale blue sapphire.	Cornelian.
Ruby.	Green jasper.
Pale ruby from Brazil.	Shoerl.
Deep sapphire.	Tourmaline.
Topaz.	Iceland agate.
Whitish topaz.	Quartz.
Spinel.	Opal.
Spathum adamantium, or the Corundum stone.	Chrysolyte.
Garnet.	Reddish yellow jasper.
Emerald.	Zeolyte.
Agate.	Fluor.
Onyx.	Calcareous spar.
	Gypsum, and Chalk.

The reader may naturally inquire whether the attraction of cohesion, and the attraction of aggregation, follow any known law of increase or decrease, a proportion to the distance; but his inquiry will not meet with any satisfactory information.

The force of gravity has been shewn to decrease inversely as the squares of the distances. But the attraction of cohesion, and that of aggregation, decrease much faster: for instance, if a force of a thousand pounds weight be required to break a certain solid, and, if then the broken parts be placed contiguous to each other, and so closely that they cannot discern the fracture; it will be found that they may be separated with the utmost facility.

It has been supposed, that those attractions decrease inversely as the cubes of the distances; but no satisfactory experiments have as yet established this supposed law.

## CHAPTER VI.

## OF THE MOTION OF THE WAVES.

THE essential facts relative to the attractions of cohesion and of aggregation having been stated in the preceding chapter, we must now explain the theory of the movements of fluids, to which we shall add several experimental observations, and shall endeavour to point out the deviations of the results of the latter from the determinations of the former.—The subject is extensive, and but imperfectly known. We shall therefore adopt conciseness as far as it may be compatible with perspicuity.

AFGB, fig. 1. Plate XII. is a bent cylindrical tube, whose parts AF, BG, are perpendicular to the horizon, and whose diameter is too large to be considerably affected by capillary attraction. Let some fluid, for instance water, be put in it; and if this fluid be put in motion, by shaking the tube once or twice, and then stopping it, the fluid will be found to continue to move some time longer; viz. it will be found to ascend in one leg, and to descend in the other leg alternately. Those vibrations, or (as they are otherwise called) *librations*, become gradually shorter and shorter, on account of the friction between the fluid and the tube, until at last the

the fluid remains perfectly at rest. But those vibrations, whether longer or shorter, have been found to be performed in equal portions of time ; and these are equal to the times in which a common pendulum, the length of which is equal to half the length of the fluid ENFGH, performs its smallest vibrations (1.)

The

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(1.) That is, equal to the times in which a cycloidal pendulum, whose length is equal to half the length of the fluid ENFGH, performs its vibrations.

When the fluid in one leg stands higher than in the other (which is the situation actually represented in the figure) divide the difference of altitude, EN, into two equal parts at A.—The fluid actuated by its gravity descends in the leg EF, whilst it ascends in the opposite leg BG ; and when it reaches the same height in both legs, which is at the level of A, it would remain there at rest ; but having acquired a certain velocity by the descent, it is thereby enabled to continue its motion, until it rises as high as the level of E, in the other leg BG, excepting a small deduction that must be made on account of the friction. When the fluid has thus ascended in the leg BG, it will again descend in that leg, and will rise anew in the other, and so on ; but performing every one of its vibrations a little shorter than the preceding one, until its motion is entirely destroyed by the friction, adhesion, &c.

The quantity of matter which is moved in this experiment, is all the fluid in the tube. The moving force is the weight of the fluid EN ; viz. the double of EM. Now this quantity of fluid, or moving force EN, does evidently

The principal use we shall make of the above described vibrations of a fluid in the bent tube, is for explaining

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increase and decrease, as the space which is to be run through by the fluid in order to reach the point of rest, or level of M; since its length is always the double of that space. For instance, when the upper part of the fluid is at Z in the leg A F, it must stand at O in the other leg; then the difference of altitude, or the moving force, is represented by Z K, which is the double of Z M; and the same thing may be said of any other situation of the fluid. But it has been proved (in Prop. X. and XV. of the note N. 1. to chap. X. Part I.) that the vibrations, whether long or short, of a cycloidal pendulum are performed in equal portions of time; for the very same reason, namely, because the moving force is always proportionate to the arch which stands between the point from which the pendulum begins to descend in every vibration, and the lowest point of the arch of vibration. Therefore the same reasoning which demonstrates this property of the cycloidal pendulum, proves the like property of the fluid moving in the tube A F G B.

Since the moving force is equal to the difference of elevation between the surface of the fluid in one leg, and that of the fluid in the other; therefore, when the fluid is all in one leg, the moving force is equal to its entire weight or gravity, which force will enable it to descend perpendicularly through a space equal to its whole length in a certain time; and since this descent is only a long vibration, and all the vibrations have been demonstrated to be performed in equal times; therefore that also is the time in which the fluid will perform each of its vibrations in the tube. But the time in

which

explaining the motion of the waves, to which they bear a great degree of analogy.

When the surface of water is smooth and at rest, if any force (be it the action of the wind, as at sea, or the fall of a heavy body, &c.) depresses the surface of it in any particular place, as at A, fig. 2 and 3, Plate XII. (the former of those figures exhibiting a section, and the latter a perpendicular view of the same object) the contiguous water will necessarily rise all round that place, as at BBB; for if a certain quantity of water be depressed below the usual level, an equal quantity must rise in some other place above that level, and the water which stands closest to the place of the original impression, will of course be moved.

The water which has thus been elevated, descends soon after in consequence of its gravity; and by the time it has reached the original level, it will have

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which a cycloidal pendulum performs each of its vibrations is equal to the time that a body would employ in descending perpendicularly by the force of gravity through twice the length of the pendulum (see the note N. 1. to chap. X. of Part I.); therefore the fluid in the tube A F G H, and a cycloidal pendulum of half the length of the fluid E N F G H, will perform their vibrations in equal times.

If the reader be desirous of determining the time of vibration of a fluid in a tube which is not of equal diameter, or whose legs are not perpendicular to the horizon, he may consult Newton's Principia, B. II. Prop. 44, 45, 46; Emerson's Fluxions, Sect. III. Prob. XX. &c.

acquired

acquired a degree of velocity sufficient to carry it lower than that level; therefore it now acts as another original moving force, in consequence of which the water will be raised on both sides of it, viz. at A, and at CCC, fig. 3 and 4, Plate XII. And for the same reason, the descent of those elevated parts will produce other elevations contiguous to them, as at BB, DD, fig. 2 and 3, and so forth. Thus the alternate rising and falling of the water in ridges will expand all round the original place of motion; but as they recede from that place, so the ridges as well as the adjoining hollows, grow smaller and smaller, until they vanish. This diminution of size is produced by three causes; viz. by the want of perfect freedom of motion amongst the particles of water, by the resistance of the air, and by the farther ridges being larger in diameter than those which are nearer.

It is likewise on account of the friction, or adhesion, amongst the particles of water, and of the resistance of the air, that in the same place the alternate elevations and depressions diminish gradually, until the water reassumes its original tranquillity; unless the external impression be renewed or continued.

One of the abovementioned ridges, or elevations, together with one adjoining cavity, is called a *wave*.

The *breadth* of the wave is the part of the horizontal line, which is occupied by a wave; and this is

is evidently equal to the distance between the tops of two contiguous ridges, or between the lowest points of two contiguous hollows.

A wave is said to have run its breadth, when its elevated part is arrived at the place where the elevated part of the next wave stood before, or when the elevated part B has moved as far as D ; or (the situations of two contiguous waves being given) when one of them is arrived at the place of the other ; and the time which is employed in this transition is called *the time of a wave's motion*.

It must not however be imagined that the water is by this means carried progressively from A towards B, D, &c. it being only the successive rising and falling, which is communicated from the original centre of motion to the next parts progressively. This may be clearly perceived by laying small floating bodies upon the surface of the water, for they will be moved up and down, but will not recede from their original places.

Now the alternate rising of the water in two adjoining places, as at B and C, has been justly considered as analogous to the vibratory motion of the water in the bent tube, fig. 1. so that the distance between the upper point of the ridge of a wave and the lowest part of its hollow, is like the length of the fluid in the tube, fig. 1. the difference at least is not very great. Therefore the wave will perform one vibration, that is, the ridge of it will become the hollow part, and the latter will be elevated, in

the same time that a pendulum of half the length of the wave, (viz. half the length of the surface of the water between the upper part of the ridge and the lowest part of the hollow) will perform one of its least oscillations. Hence the motion of waves is regular, or the risings and fallings of the water in the same place are performed in equal portions of time, as is the case with the fluid in the tube, fig. 1.

But this time of vibration is half the time in which a wave will run its breadth ; for in order to run that breadth, the ridge must come, not to the place where the next hollow stood, but to the place where the next ridge stood. Therefore a wave will run its breadth in the same time that a pendulum of half its length will perform two of its least vibrations ; or to the time in which a pendulum equal to four times that length, (viz. equal to the length of the surface B C D) will perform one vibration ; since the times, in which pendulums of different lengths perform their vibrations, are as the squares of their lengths.

When the waves are broad and do not rise high, then the abovementioned length, B C D, will not differ much from the breadth of the wave ; and in that case the wave will run its breadth in the same time that a pendulum, whose length is equal to that breadth, performs one of its vibrations. Hence, if the breadth of a wave be 39,1196 inches\* ; then

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\* Such being the length of the pendulum which vibrates seconds. See page 196. vol. I.

that

that wave will move on at the rate of 39,1196 inches per second of time; that is, at the rate of 195 feet per minute, nearly.

It will easily be conceived that the waves rise higher or lower, according to the power of the original moving force; for the more water is displaced by that force, the greater quantity of it must be elevated above the usual level; and of course the breadth of the waves is likewise greater.

It seems to be pretty well determined from a variety of experiments and observations, that the utmost force of the wind cannot penetrate a great way into the water; and that in great storms the water of the sea is slightly agitated at the depth of 20 feet below the usual level, and probably not moved at all at the depth of 30 feet or five fathoms\*. Therefore the actual displacing of the water by the wind cannot be supposed to reach nearly so low; hence it should seem that the greatest waves could not be so very high as they are often represented by accurate and creditable navigators. But it must be observed that in storms, waves increase to an enormous size from the accumulation of waves upon waves; for as the wind is continually blowing, its action will raise a wave upon another wave, and a third wave upon a second, in the same manner as it raises a

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\* Boyle's works, folio edition, vol. III. Relations about the bottom of the Sea. Sect. III.

wave upon the flat surface of the water. In fact, at sea, a variety of waves of different sizes are frequently seen one upon the other, especially whilst the wind is actually blowing. And when it blows fresh, the waves, not moving sufficiently quick, their tops, which are thinner and lighter, are impelled forward, are broken, and turned into a white foam, particles of which, called the *spray*, are carried a vast way.

Waves are circular, or straight, or otherwise bent, according as the original impression is made in a narrow space nearly circular, or in a straight line, or in other configurations. In open seas the waves generally are in the shape of straight furrows, because the wind blows upon the water in a parallel manner, at least for a long apparent tract.

When the water receives several impulses at the same time, but in different places, then the waves which proceed from those places must necessarily cross each other.—By this crossing the waves do not disturb each other; but they follow their proper directions, by passing one upon the other. Thus if two stones be thrown upon the surface of stagnant water nearly at the same time, but at a little distance from each other; the circular waves which proceed from those places will be clearly perceived to cross each other, and to follow their peculiar courses. The reason of which is, that the same cause which produces the alternate rising and falling of the water upon the surface of otherwise stagnant water, must operate

operate in the same manner, and must produce the like effect on the surface of another wave.

When a wave meets with an obstacle which is straight and perpendicular, such as a wall, a steep bank, as R S, fig. 3. then the wave is reflected by it, and the shape of the reflected or retrograde wave, is the reverse of what it would have been on the other side of the obstacle, had the obstacle not existed. Thus in fig. 3. the reflected wave  $v t v$  has the same curvature as it would have had at  $xyx$ , if the obstacle had not reflected it; for the middle part of the curvature must naturally meet the obstacle, and must be reflected by it first; so that this part will be found at  $t$ , when the adjoining parts which are reflected after it are at  $vv$ , &c.—And since waves will cross without obstructing each other, the reflected waves will proceed from the obstacle, and will expand all round, &c.

When the bank or obstacle is inclined to the horizon, as is frequently the case on the shores of the sea; then the reflection of the waves is disturbed, and it is often absolutely destroyed by the friction of the water upon the ground.

If the obstacle be such as to reflect a part only of the wave, such as a stone or a post, which is surrounded by the water; then the wave will be partly reflected in shapes and directions which differ according to the form and size of the obstacle, whilst the rest of the wave will proceed in its original direction.

When

When a hole in an obstacle permits part only of a wave to go through, as at Z, fig. 3. then circular waves will be formed on the other side of the obstacle, whose centre is the hole ; for in fact those waves owe their origin to the motion of the water in that place only.

The same causes which raise water into waves, must evidently produce the like effect on other fluids, but in different degrees, according as the fluid is more or less heavy, as its particles adhere more or less forcibly to each other, and probably likewise according as there is a greater or less degree of attraction between the fluid and the other body, which gives it the impulse.

When a stone or other heavy body is dropped on the surface of oil, the waves are not nearly so high, nor so quick, neither do they spread so far as the waves of water. This effect is evidently owing to the clamminess, or great degree of adhesion between the particles of the oil.

If the waves upon oil be attempted to be raised by the force of wind, it will be found very difficult to succeed even in a moderate degree. This difficulty is in a great measure owing to the attraction between the particles of oil ; but besides this, there may be less attraction between oil and air, than between the latter and water ; for water always contains a certain quantity of air ; and if it be deprived of that air by means of boiling or otherwise, a short

exposure to the atmosphere will enable the water to reimbibe it.

It is likewise probable, that the surface of water, even when stagnant, may not be so smooth as the surface of oil; so that the wind may more easily catch into the inequalities of the former than of the latter.

It is remarkable that the effect of the wind upon water may in a great measure be prevented or moderated, by spreading a thin film of oil on the surface of the water.

No great quantity of oil is required for this purpose; for, though oil be very clammy and adhesive to almost all other bodies; yet when dropped upon water, it will instantly spread and extend itself over a vast surface of water; and it will even drive small floating bodies out of its way, acquiring, as it seems, a repulsive property amongst its own particles.

This repulsion may be shewn in the following amusing manner: Cut a light shaving of wood, or of paper, in the form of a comma, or of the size and shape of fig. 5. Plate XII. smear it with oil, then place it upon the surface of a pretty large piece of smooth water; and the bit of wood or paper will be seen to turn round in a direction contrary to that of the point A, which is occasioned by the stream of oily particles issuing from the point and spreading themselves over the surface of the water.—This experiment will not succeed in a basin or other small

vessel full of water, wherein the particles of oil have not room enough to expand themselves.

If a heavy body be dropped on the surface of water which is thus covered with a film of oil, the waves will take place in the same manner as if there were no oil. But the blowing of the wind will have little or no effect upon it. In this case the oil seems to act between water and air, in the same manner as it acts between the moving parts of mechanical engines; viz. it lubricates the parts, and renders the motion free and easy.

But whether this be the real explanation or not, the fact is not less true than surprising; and a very useful consequence has been derived from it, namely, a method of stilling the waves of the sea in certain cases.

It is expressly mentioned by Plutarch\* and Pliny†, that the seamen of their times used to still the waves in a storm, by pouring oil into the sea. But since the revival of learning, though several observations relative to it are to be found in accounts of voyages, &c. yet I do not know that any notice has been taken of this account by any philosophical writer, previous to the late celebrated Dr. Franklin, who collected several accounts relative to the sub-

\* Quæst. Nat.

† Hist. Nat. lib. ii. c. 103.

ject, and made a variety of experiments upon it, the sum of which is as follows \*.

A small quantity of oil, for instance, a quarter of an ounce, will spread itself quickly and forcibly upon the water of a pond or lake, to the extent of more than an acre; and if poured on the windward side, the water will thereby be rendered quite smooth as far as the film of oil extends, whilst the rest of the pond may be quite rough, from the action of the wind.

If the oil be poured on the leeward side, then the force of the wind will in a great measure drive it towards the bank. Besides which, the experiment is frustrated by the waves coming to that side already formed; for the principal operation of the oil upon water is, as it seems, 1st. to prevent the raising of new waves by the wind; and 2dly. to prevent its driving those which are already raised with so much force, as it would if their surface were not oiled..

Such experiments at sea are evidently attended with a great many difficulties; but in particular cases essential advantages may be derived from the use of oil, and several instances of its having been

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\* See his paper on the stilling of waves by means of oil, in the Phil. Transactions, vol. LXIV. or in his miscellaneous papers.

of very great service, are recorded\*. "We might," says Dr. Franklin, "totally suppress the waves in any required place, if we could come at the windward place, where they take their rise. This in the ocean can seldom if ever be done. But perhaps something may be done on particu-

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\* Mr. Tengnagel, in a letter to Count Bentinck, dated Batavia, January the 5th, 1770, says, "Near the Islands Paul and Amsterdam, we met with a storm which had nothing particular in it worthy of being communicated to you, except that the Captain found himself obliged, for greater safety in wearing the ship, to pour oil into the sea, to prevent the waves breaking over her, which had an excellent effect, and succeeded in preserving us." Phil. Transactions, vol. LXIV. page 456.

It has been remarked in Rhode Island, that the harbour of Newport is ever smooth whilst any whaling vessels are in it; which is, in all probability, owing to the fish-oil that may come out of them.

It is said to be a practice with the fishermen of Lisbon when about to return into the river (if they see before them too great a surf upon the bar, which they apprehend might fill their boats in passing) to empty a bottle or two of oil into the sea, which will suppress the breakers, and allow them to pass safely.

In various parts of the coast of the Mediterranean, and elsewhere, it is a practice of the fishermen, to sprinkle a little oil upon the water, which smooths the surface of the water that is ruffled by the wind, and thus enables them to see and to strike the fish.

" lar

“ lar occasions, to moderate the violence of the  
“ waves, when we are in the midst of them, and  
“ prevent their breaking, where that would be in-  
“ convenient.

“ For ‘when the wind blows fresh, there are con-  
“ tinually rising on the back of every great wave,  
“ a number of small ones, which roughen its sur-  
“ face, and give the wind hold, as it were, to push  
“ it with greater force. This hold is diminished  
“ by preventing the generation of those small ones.  
“ And possibly too, when a wave’s surface is oiled,  
“ the wind, in passing over it, may rather in some  
“ degree press it down, and contribute to prevent  
“ its rising again, instead of promoting it.”

Light, volatile, or etherial oils, like ether, spirit of turpentine, &c. do not possess the same proper-  
ty as fat oils, such as olive oil, lin-seed, rape-seed  
oil, train-oil, &c.

## CHAPTER VII.

OF THE MOTION OF FLUIDS THROUGH HOLES,  
PIPES, CANALS, &c.

THE insufficiency of the common theory to account for the phenomena which have been observed relatively to fluids in motion, suggests the expedient of stating the results of the principal and most authentic experiments which have hitherto been made in this branch of natural philosophy; it being from a collection of well established facts, that a useful set of theoretical propositions, or natural laws, may hereafter be deduced. We shall nevertheless briefly prefix the leading propositions of the common theory, in order that the deviations of its results from those of actual experiments, may be rendered more evident to the reader. And in this place it seems proper to observe, that the imperfections of this theory, which in truth is partly established upon facts, must be attributed not to any deficiency in the mode of reasoning, but to the want of adequate principles to establish that reasoning upon.—The demonstration of any proposition, whether in mathematics or in any other subject, does only shew the natural, necessary, and uncontrovertable dependence of one idea upon the next, throughout the whole chain of ideas, which inter-

vere between the assertion of the proposition, and certain principles or axioms. Therefore the demonstration may be strictly just and proper, yet the proposition may be either true or false, according as the principles upon which it is established are true or false; and according as all the principles upon which that proposition depends, or some of them only, have been taken into the account.

Now with respect to the theory of fluids in motion, the defect arises from the imperfect knowledge of the principles, or the circumstances upon which the phenomena depend.

According to the common theory. I. When a fluid is conveyed through a pipe of an uniform bore, or a channel of an uniform shape and capacity, as in fig. 6. Plate XII. the velocity of the fluid is the same in every section of it; viz. in the same time an equal quantity of fluid will pass through A B, or through D C, or through E F, &c. But if the said channel or pipe be narrower at some places than at others, then the velocities of the fluid which passes through it will be different; viz. at different sections the velocities will be inversely as the areas of the sections. Thus, suppose that in the channel, fig. 7. Plate XII. the aperture, or the area of the section A B, is equal to half the area of the section C D; then the velocity of the fluid at A B will be double the velocity of the fluid at C D; for since the channel, or pipe, remains always full, it is evident that in the same time an equal quantity

of fluid must pass through CD; as through AB. But at AB the capacity of the pipe is half that at CD; therefore the fluid must move through AB as quick again as it does through CD; since, if it moved with the same velocity through both places, the quantity of fluid which passed through AB in a certain time, would be the half of what passed through CD; in which case the channel would not remain equally full.

II. If a small aperture be made in the bottom, or in the side of a vessel full of water and open at top; equal quantities of water will flow out of it in equal portions of time, provided the vessel be kept continually full, by means of a proper supply of water. But if the vessel be not supplied with water (in which case the quantity of water in it will be gradually diminished, until its surface arrives at the aperture); then the water will flow out of the aperture with a velocity which is continually retarded; and which has been found to be nearly equal to the velocity which a body would acquire in falling through a space equal to half the perpendicular altitude of the fluid above the aperture; hence the velocity is as the square root of that altitude. (See what has been said concerning the descent of bodies in Chap. V. Part I.)

III. If in the bottoms or in the sides of equal vessels containing water, equal apertures be made, but at different distances from the surface of the water; then the quantities of water which will flow in a given

given time, will be as the square roots of the altitudes of the water above the apertures respectively; since, by the preceding paragraph, the velocities are in that proportion.

IV. In equal vessels full of water, if unequal apertures be made at equal distances below the surface of the water, then the quantities of water which flow in a given time, are nearly as the areas of the apertures. Hence, if cylindric vessels, full of water, be equal in every respect, except their having unequal apertures, the times in which they are emptied will be inversely as the areas of their apertures; and if they are equal in every other respect, except in their diameter, then the times of emptying themselves will be as their contents respectively.

V. Let a vessel of a cylindric or prismatic form be set up perpendicularly to the horizon, and an aperture be made in its bottom; then if the vessel be kept constantly full by a supply of water, twice the quantity of water will flow out of the aperture in the same time in which the vessel would empty itself if it were not supplied with water.

The demonstration of those propositions might be easily derived from the doctrine of motion already explained\*: but the determinations of those propositions deviate more or less from the results of actual experiments; and this deviation is owing

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\* See D. Bernoulli's and D'Alembert's Theories. Also

to the following causes or concurring circumstances, which, on account of their uncertain or fluctuating nature, have not yet been sufficiently investigated.

These are the peculiar natures of fluids, which vary according to the temperature, purity, &c.—the attraction of aggregation, or (as it is otherwise called) the *corpuscular attraction*;—the attraction of cohesion; the friction against the sides of the vessels; the resistance of the air; the size of the vessel in proportion to the aperture; the shape of the aperture; the different directions in which the various parts, or (as they are otherwise called) the various *filaments* of the fluid of the same vessel run towards the aperture; and the vortices or irregular motions which are communicated to the fluid by a variety of causes; even by an obstacle to the stream at some distance from the aperture.

Actual experiments accurately performed, and observations attentively made on the motion of fluids, have shewn the following facts, which for the sake of perspicuity we shall arrange under three heads; viz. first, those which relate to fluids running through open channels; secondly, those which relate to the running of fluids out of apertures; and thirdly, those which relate to the jet itself out of the aperture.

I. When water runs through a channel of an uniform shape, and open at top, as in fig. 6. Plate XII. the water does not move with the same

throughout the whole capacity or width channel; but its motion is swifter through middle of the upper surface, than nearer the bottom, where its velocity is partly by the friction, adhesion, &c.

In the channel is not of an uniform shape, n it is interrupted by obstacles, the velocities water at different transverse sections are not ly as the areas of those sections; but they more or less from that ratio, according to the if the stream, and the peculiar configurations channel, and the obstacles which force differ- lents or filaments of the stream to run with nt velocities in different directions, which itly cross and check each other. Thus in the , fig. 8. Plate XII. the water in passing h the narrow part A B, will move with in- l velocity, and after having passed that part, mentum will enable it to move on in the it direction *ed*; but in consequence of the ion of water to water, it will drag part of the at *e* towards *d*, which occasions a depression of ter about *e*; hence the water from the ad- parts *f*, *g*, runs to supply that defect, and curvilinear or whirling motion *dfge*, is pro- .—These whirling motions are called *eddies*. this means the velocity of the stream, in the on *ed*, is gradually checked, and its motion municated to the contiguous water in the part Z R.—Farther on, the greatest part of the

the stream strikes against the obstacle OS, which being aslant to its direction, destroys part of its force. With the other part of that force, (agreeably to the law of the composition and resolution of forces) the water runs in the direction OT, and strikes against the bank at T, about which place it meets the other part of the stream, which runs in the direction dT, and thus by crossing, they check each other, &c.

The same observations may be applied to the inequalities of the bottom. Thus, for instance, let A B C, fig. 9. Plate XII. represent the bottom of a channel which is hollowed at DB. EF represents the surface of the water. Now the lower part of the stream, after having passed along the hollow from D to B, will, agreeably to the laws of motion, tend to continue its motion in the last direction, viz. in the direction from B towards F; and in fact at F, the surface of the water will be seen a little elevated above the rest. In this case two portions of the same body of water run in different directions, viz. one part from B towards F, and another part from AE towards CF; hence they must partly obstruct each other.

Such eddies and different directions may be clearly observed in almost any river or natural stream of water, especially when the water contains floating particles of earth and other solids. By pouring a small quantity of red wine, or of milk, into a basin full of water, a clear view of those eddies,

eddies, &c. may be exhibited in an easy and familiar way. And the experiment may be varied by pouring the milk either in the direction of the side, or towards the centre of the basin; as also against a spoon, which may be made to represent an obstacle either against the side or at the bottom of the vessel.

The various changes and other phenomena which take place in rivers, are almost all depending upon the directions and the momenta of different parts of the stream; so that by a thorough examination of the local causes which produce them, the methods of using them advantageously, or of remedying the inconveniences that arise therefrom, may be frequently discovered.—This is one of the essential advantages which mankind derives from the knowledge of hydrostatics.

The water which runs in consequence of its gravity from a higher to a lower part of the surface of the earth, in a channel generally open at top, is called a *river*.

A river which flows uniformly and preserves the same height in the same place, is said to be *in a permanent state*. But such rivers are seldom if ever to be found.

From what has been said above it is evident that the water of a river does not flow with the same velocity through the whole width of the river. The line in which the water moves with the greatest velocity, is called *the Thread of the river*, and this

thread

thread seldom lies in the middle of the river, but it generally comes nearer to one side than to the other, according to the nature of the impediments, and of the configuration of the banks.

Rivers owe their origin to the natural springs, or mountains, or other elevated parts of the surface of the earth, whence the water descends through such openings as nature, and sometimes art, offers to it. The waters of various springs, by thus running towards the same valley, frequently meet and form one stream, which, by passing continually over the same place, hollows the ground and forms itself a channel, which, according to the nature and disposition of the ground, goes into various directions, and alters its velocity, but always descending from a higher to a lower place, until at last it runs either into another river or into the sea, after having sometimes passed over a tract of some thousands of miles\*.

The

\* The proportional lengths of course of some of the most noted rivers in the world are shewn nearly by the following numbers.

Mr. Rennell's paper, Phil. Trans. vol. 71st, p. 90.

#### European Rivers:

Thames	—	—	—	I
Rhine	—	—	—	5 $\frac{1}{2}$
Danube	—	—	—	7
Volga	—	—	—	9 $\frac{1}{2}$

Asiatic

The velocity of the water of a river ought to increase in proportion as it recedes from its source; but the numerous causes of retardation, which occur in rivers, are productive of very great irregularities; and it is impossible to form any general rules for determining such irregularities.

The unequal quantities of water (arising from rains, from the melting of snow, &c.) which are conveyed by rivers at different seasons, enlarge or contract their widths, render them more or less rapid, and change more or less the form of their beds. But independent of this, the size and form of a river is liable to be continually altered by the

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**Asiatic Rivers:**

Indus	—	—	—	5 $\frac{1}{2}$
Euphrates	—	—	—	8 $\frac{1}{2}$
Ganges	—	—	—	9 $\frac{1}{2}$
Burramooter	—	—	—	9 $\frac{1}{2}$
Nou Kian, or Ava River	—	—	—	9 $\frac{1}{2}$
Jennisea	—	—	—	10
Oby	—	—	—	10 $\frac{1}{2}$
Amoor	—	—	—	11
Lena	—	—	—	11 $\frac{1}{2}$
Hoanho (of China)	—	—	—	13 $\frac{1}{2}$
Kian Keu (of ditto)	—	—	—	15 $\frac{1}{2}$

**African River:**

Nile	—	—	—	12 $\frac{1}{2}$
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**American Rivers:**

Mississipi	—	—	—	8
Amazons	—	—	—	15 $\frac{1}{2}$

usual

usual flowing of its waters, and by local peculiarities. The water constantly corrodes its bed wherever it runs with considerable velocity, and rubs off the sand, or other not very coherent parts. The corrosion is more remarkable in that part of the bottom, which is under the *thread* of the river, or where the water descends suddenly from an eminence, as in a *cascade* or *water-fall*. The sand thus raised is deposited in places where the water slacks its velocity, and there by degrees an obstacle, a bank, and even an island, is formed, which in its turn produces other changes. Thus a river sometimes forms itself a new bed, or it overflows the adjacent grounds.

In some places we find that an obstacle, or a bent on one side will occasion a corrosion on the opposite bank, by directing the impetus of the stream towards that bank. Thus, from divers causes, whose concurrence in different proportions, and at different times, forms an infinite variety, the velocity of rivers is never steady or uniform.

“ One of the principal and most frequent causes,” says the very able Professor Venturi, “ of retardation in a river, is also produced by the eddies which are incessantly formed in the dilatations of the bed, the cavities of the bottom, the inequalities of the banks, the flexures or windings of its course, the currents which cross each other, and the streams which strike each other with different velocities. A considerable part of the force of the current is thus employed

employed to restore an equilibrium of motion, which that current itself does continually derange \*."

The use of rivers is immense.—They fertilize the ground ;—they supply mankind and other animals with water, an article absolutely necessary to life ;—they serve as tools for a variety of purposes, such as for giving motion to mills, pumps, and other engines ; they serve for conveying the articles of commerce, and for facilitating the intercourse between inland countries. But I need not enlarge on this subject, which is too obvious to need illustration, and which in the hands of many able writers, has often been adduced as a proper instance of the infinite wisdom of Providence †.

II. The running of water, or other fluid, out of a vessel, or reservoir, through any aperture, is likewise influenced by some of the above-mentioned causes of retardation, as also by other peculiar circumstances.

The stream of water which issues out of a hole, tends to carry away in its direction any other fluid, and any sufficiently light solids, which may happen to

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\* Exp. Enquiries on the lateral communication of motion to Fluids.

† For farther information respecting rivers, see s'Gravende's Nat. Phil. B. III. chap. x. Rennell's Account of the Canes, &c. in the Phil. Trans. vol. 71<sup>st</sup>. Guilielmini, *Ua Natura de Fiumi, &c.*

be near it. This is what Professor Venturi calls *the lateral communication of motion in fluids*. But by this lateral communication of motion to contiguous bodies, the celerity of the fluid itself is checked more or less, and its course is partly diverted from the course which it would otherwise follow.

Thus in fig. 10. Plate XII. which represents the upper surface of two vessels contiguous to each other, and full of water, as high as the hole or aperture A.—If by pouring more water into the vessel B, a stream of water be caused to flow through A, into the vessel C; this stream will carry away the water from the parts *e e*, towards C. But the depression, or deficiency, of water at *e e*, is replaced by the water from the adjacent parts *d d*, which are replenished from the next, and so on. This produces eddies at *e d*, *e d*. This phenomenon may be rendered more apparent if a little milk be at times thrown into the vessel B, or if light and small bodies float on the surface of the water.

When a stream comes out of a hole, as at A, fig. 11. Plate XII. if a thread, a feather, or other light body be placed very near it, the tendency of the stream to carry it away towards B, may be clearly perceived.—The following experiment will shew this property in a manner still more convincing.

Let a vessel be made in the form of the lateral view A D B, fig. 12. Plate XII. viz. open at top,

top, and having one slant side. Let a cylindrical pipe of about half an inch in diameter, and upwards of a foot long, proceeding from a vessel C, come straight down into the vessel ADB, and there let its termination FS, be bent in the direction of the slant side BD. This done, fill the vessel ADB with water, then pour water into the vessel C; so that the water running down the pipe EFS, may form the jet SK. It will be found that the water of the vessel ADB, is carried away by the stream, and this vessel is thereby almost entirely emptied.

The same communication of motion may be perceived within a tube; as is shewn by the following experiment of Professor Venturi.

To an aperture on the side of the vessel AB, fig. 13. Plate XII. a pipe CD, 1,6 inches in diameter, and little more than 5 inches long, was adapted in an horizontal direction. At E, distant 0,71 inches from the side of the vessel, a bent glass tube EFG, was joined, whose cavity was opened into that of the pipe, whilst its other extremity was immersed in coloured water, which was contained in a small vessel G. When by pouring water into the vessel AB, a stream was made to flow out at D, the coloured water was seen to rise considerably in the lower leg of the glass tube.

This experiment being repeated, when the descending leg FG of the glass tube was only 6,4 inches longer than the ascending leg EF. The coloured water of the vessel G, rose through the glass tube,

and mixing with the other water, flowed with it out of the pipe at D ; and in a short time the vessel G was emptied.

This sort of suction or communication of motion takes place, whether the discharging pipe C D, be directed horizontally, or downwards, or upwards\*.

When

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\* In a descending stream this power of communicating motion to the adjacent bodies, is rendered more active by, or rather it may be better explained, on account of, the tendency that a descending stream has to divide itself into separate portions, and of the pressure of the atmosphere. This tendency is owing to the acceleration of falling bodies. Suppose, for instance, that there comes out of a hole at the bottom of a vessel, an ounce of water per second of time; then, when the first ounce has been falling during two seconds, it must have percurried a space equal to 4 times 16 feet nearly; whereas the second ounce of water having come out one second later, has been falling during one second only, and of course it must have run through 16 feet only; therefore the distance of the first ounce of water from the next is equal to 3 times 16 feet.

At the end of three seconds, the first ounce of water must have passed along 9 times 16 feet; whilst the second ounce of water has passed along 4 times 16 feet; so that the distance between the first ounce of water and the second, now is 5 times 16 feet; which one second before was only 3 times 16. Therefore the two ounces of water, or any contiguous parts of the descending stream (for the same reasoning may be evidently applied to any portions, or to

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When water runs out of an aperture on the thin side or bottom of a vessel, as at A, fig. 11. Plate XII. the size of the aperture being very small in

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the simple particles, of a fluid, and to any portions of time) have a constant tendency to separate, and they do actually separate into irregular masses, when the stream descends through a sufficient space ; and at the same time the air forces in any contiguous bodies that are sufficiently moveable, or introduces itself between the interstices, and is driven downwards by the succeeding parcels of water.

This is the reason which, when a fluid, (such as beer, &c.) is poured out of one vessel into another in a long stream, mixes a considerable quantity of air with the liquor, and produces the froth. Upon this principle the machine for blowing the fire of a furnace, by means of a fall of water, is constructed, as will be described in the sequel.

The resistance of the air, the adhesion of water to water, and the various shape of the stream, render the separation of its parcels not very regular, and generally spread or divide into longitudinal filaments.

The rain-water which in some places flows from the tops of houses through spouts, and falls in the streets, in its fall separates into parcels, and strikes the ground with distinct blows and ample surface.

“ I went,” says *Professor Venturi*, to the foot of the cascades “ which fall from the glaciere of la Roche-Melon, on the “ naked rock at la Novalese, towards Mount Cenis, and “ found the force of the wind to be such as could scarcely “ be withstood. If the cascade falls into a basin, the air is “ carried to the bottom, whence it rises with violence, and “ disperses the water all round in the form of a mist.”

proportion to the side or bottom of the vessel; the stream A B, is not throughout of the shape of the aperture, nor is it of an uniform size. When the aperture is circular, the distance of the narrowest part of the stream, from the inside surface of the vessel, is about equal to the diameter of the aperture. This narrowest part of a stream has been called *the contracted vein* (*vena contracta* by Newton) from which place forwards the stream grows larger, and sometimes divides itself into different parcels.

The diameter of the contracted vein ; that is, of the narrowest part of the stream, is subject to a little variation ; but from a mean of various measurements, it appears equal to 81 hundredths of the aperture ; so that if the diameter of the aperture be one inch, the diameter of the *vena contracta* will be 0,81 of an inch \*.

This contraction of the stream is undoubtedly owing to the various directions in which the fluid comes along the sides, and from every part of the vessel, towards the aperture, as is indicated by fig. 14. Plate XII. and in fact, when the aperture is very large in proportion to the size of the vessel, the contraction of the stream is not so apparent. Also, if the aperture be not in a plate sufficiently

\* From the measurements of Newton, Poleni, Micheliotti, Bossut, and Venturi.

thin, the *vena contracta* will not be perceived; for since the distance of that contraction from the inner surface of the vessel is about equal to the diameter of the aperture, if the thickness or rather the length of the aperture, exceed its diameter, as when a pipe is added to the aperture; then the contraction, or the tendency to form the contraction, takes place within that thickness, or within that length of pipe.

The various filaments of the fluid, which run from every part of the vessel in oblique directions towards the aperture, partly cross each other at the *vena contracta*; and this crossing, or tendency to cross, is one of the causes which enlarge the stream beyond that place.

The velocity of the water is not the same in every part of the stream; for since the same quantity of water must pass through every transverse section of it in a given time, the velocity must be inversely as the area of each transverse section. Therefore at the *vena contracta* the velocity is greater than at the aperture. Now it has been found from experiments, that the velocity of the fluid at the aperture, supposing this to be circular, and to be made in a very thin plate, is very nearly such as a body would acquire by falling perpendicularly from an altitude equal to half the perpendicular height of the fluid in the vessel, above the centre of the aperture; and that the velocity at the *vena contracta* is such as a body would

acquire by falling perpendicularly from that whole height (2.)

If to the circular aperture on the side of a vessel, there be applied a cylindrical pipe of the same diameter, and whose length is equal to from two to

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(2.) The velocity of the fluid at the aperture may be deduced from the quantity of fluid which is found upon trial to be discharged in a given time ; and this is to be done in the following manner.

Call the area of the aperture  $a$  ; let  $q$  represent the quantity of fluid which has been discharged in the time  $t$ , which means the number of seconds of time ; and let  $x$  express the velocity ; that is, the space described in one second of time. Then imagining that all the fluid  $q$  is formed into a cylinder, whose base is  $a$ , and height  $= b$ , we shall have  $q = ah$  ; whence  $b = \frac{q}{a}$  ; so that the fluid with the first velocity  $x$ , would have run through the height of the cylinder, viz. through the  $\frac{q}{a}$  in the time  $t$ . Therefore,  $t'' : 1'' :: \frac{q}{a} : \frac{q}{at}$   $\equiv$  the space described in one second, or  $x$ , the velocity sought.

The proportion between the velocity at the *vena contracta*, and at the aperture, is found by saying, as the area of the former is to the area of the latter, so is the velocity at the aperture to the velocity at the *vena contracta*; viz. (since those areas are nearly similar, and similar areas are to each other as the squares of their homologous sides, or of their diameters)  $\sqrt{0,81}^2 : 1^2 :: 0,6561 : 1 :: 1 : 1,52$ , which, the reader is requested to observe, is nearly the ratio of  $1 : \sqrt{2}$  ; the square root of 2 being  $1,414$ , &c.

four times that diameter, as A B, fig. : 5. Plate XII. then a greater quantity of water will be discharged through it than through the simple aperture in an equal portion of time, every other circumstance remaining the same; the quantities of fluid discharged in those two cases being as 133 to 100 nearly.—The pipe A B, or any other prolongation of whatever shape it may be, which is adapted to the aperture of a vessel, &c. has been called *the adutage*, probably from its property of promoting the discharge of fluid.

It has been also observed, that the discharge in a given time is the same, whether the aperture be furnished with the above-mentioned cylindric pipe, or with the pipe represented in fig. 16. Plate XII. which differs from the former only by its having, close to the side of the vessel, a contraction nearly of the shape of the contracted vein.

If the last mentioned pipe be cut off at the contraction, and the first conical part only be left affixed to the aperture, as in fig. 17. Plate XII. then the discharge of water is rather less than from a simple aperture; but it is probable that it would be quite the same, were it possible to make the conical adutage exactly of the shape of the natural contracted vein; excepting however the effect of friction.

If to this conical part a cylindrical tube of the diameter of the small part of the conical pipe, be applied, as in fig. 18. Plate XII. the discharge of fluid will thereby be diminished, and more so according

according as the length of the cylindrical part is increased.

If to the small conical part of the adjutage, fig. 17. a diverging pipe, viz. another conical tube be applied, as in fig. 19. Plate XII. the discharge of water will thereby be increased within a certain limit \*. And if between those two conical parts a cylindric tube be interposed, as in fig. 20. then the discharge is diminished again; but not nearly so much as if the outer conical part were removed †.

A re-

\* Experience shews that the divergency of this termination must not be increased beyond a certain degree, for in that case it will prove rather disadvantageous than useful. It appears that when the divergency is greater than an angle of 16 degrees, the effect ceases entirely; and that the greatest effect takes place; that is, the greatest quantity of fluid is discharged, when the divergency is equal to an angle of about three degrees.

† The effects produced by the above-mentioned adjutages, and the exact quantity of water which is discharged through certain apertures, may be derived from the results of Professor Venturi's Experiments, which are concisely subjoined.—The measures are English, except the contrary be expressed.

The same quantity of water (viz. 4 French cubic feet, equal to 4,845 English cubic feet) flowed out of the same vessel, or reservoir, which was kept constantly full, through the following adjutages, in the annexed times, which are expressed in seconds. The altitude of the water in the vessel above

A remarkable advantage is derived from the knowledge of this fact, which is, that when water is conveyed through a straight cylindrical pipe of whatever length it may be, the discharge of water may be increased by only altering the shape of the terminations of that pipe, viz. by making the end of the

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above the level of the centre of the outer aperture of the adjutage was always equal to 32,5 French inches, or 34,642 English inches.

Through a simple circular aperture, in a thin plate, the diameter of the aperture being equal to 1,6 inches, in — — — 41".

Through a cylindrical tube of the same diameter as above, and 4,8 inches long. Fig. 15. in 31".

Through the tube, fig. 16. which differs from the preceding, by having the contraction in the shape of the natural contracted vein, in 31".

Through the short conical adjutage, fig. 17. which is only the first conical part of the preceding, in — — — 42".

Through the pipe, fig. 18. which consists of a cylindrical tube, adapted to the small conical end of fig. 17. and of that diameter, A D being 3,2 inches long, in — — — 42",5.

Through the like adjutage, but longer, A D being 12,8 inches, in — — — 45".

Through the like, still longer, A D being 25,6 inches, in — — — 48".

Through the adjutage, fig. 22. which consists of the simple tube of fig. 15. placed over the conical part of fig. 17. in — — — 32",5.

Through

the pipe, which is close to the reservoir, or the entrance to it, of the shape of the contracted vein, (as at A, fig. 21.) the dimensions of which have been stated in p. 182; and by making the other extremity BC of the pipe, in the shape of a truncated cone, whose length BC may be equal to nine times the diameter of the cavity at B; and whose aperture at C may be larger than the diameter at B, in the ratio of 18 to 10.—By this means the quantity of water which is discharged in a given time, will be more than doubled; viz. the quantity of water discharged by the simple cylindric pipe, is to the quantity of water which is discharged by the same pipe with the above-mentioned conical terminations, as 10 is to 24 nearly.

The effect of the above-mentioned adjutages is the same, whether they be adapted to the side or to the bottom of the vessel, or in any other direction, provided every other circumstance be the same; such as the capacity and form of the

Through the double cone, fig. 19. the dimensions of which are, AB = EF = 1,6 inches, AC = 0,977 inches, CD = 1,376 inches, and the length of the outer cone = 4,351 inches, in — — — 27',5.

Through the adjutage, fig. 20. consisting of a cylindrical tube 3,2 inches long, and 1,376 inches in diameter, interposed between the two conical parts of the preceding, in — — 28',5.

reservoir,

reservoir, the altitude of the water above the level of the centre of the outer opening of the adju-tage, &c.

All flexures, and all sorts of internal contractions, elongations, enlargements, and projections, of the conducting pipe, diminish the quantity of discharge more or less, according to the number and form of such irregularities, sharp angular bendings hindering the motion of the fluid, more than those of a regular curvature. The cause of this retardation is undoubtedly owing to the eddies, and to the crossings of the various filaments of the fluid, which, according to what has been said above, must necessarily take place at those irregularities. This may be rendered sufficiently evident, if an irregular glass pipe be applied to a pretty large vessel full of water, and with the water there be mixed some particles of pounded amber, or other substance, whose specific gravity differs but little from that of water.—All eddies and cross directions must unavoidably destroy part of the moving force.

Whenever an irregularity of the shape of the aperture, or some particular conformation of the vessel, compel the particles of the fluid to run obliquely towards an aperture, a circular motion is soon communicated to the fluid, and an hollow whirl is formed above the aperture. By the circular motion the particles of the fluid acquire a centrifugal force, in consequence of which they tend to recede from the centre or from the axis of motion, where

where of course a hollow is formed, which is larger or smaller, according as the rotation of the fluid is more or less rapid. When this whirling motion is pretty considerable, if any light bodies float upon it, those bodies will be readily drawn downwards towards the aperture; for, since the specific gravity of the fluid is greater than that of the bodies, the fluid will acquire a greater degree of centrifugal force, and will recede farther than those bodies from the axis of the whirl. See chap. IX. of Part I.

III. The laws of projectiles, which have been explained at the end of the first part of these elements, are applicable to fluids as well as to solids, excepting some peculiarities which are easily suggested by the nature of fluids. Therefore the principal phenomena relative to the direction, and the length of a stream of fluid which issues out of an aperture, may be determined by the laws of projectiles.

When fluids, like solids, are projected in an oblique direction, they describe parabolic paths; for they are at the same time acted upon by the projectile force, and by the force of gravity, excepting the deviation from that parabolic curve which is occasioned by the resistance of the air. But when they are projected perpendicularly upwards or downwards, then they move in straight lines; and yet those straight lines might be considered as parabolas grown infinitely narrow.

When

When a fluid comes out of a hole in the thin-side of a vessel, the velocity of projection must be reckoned equal to that of the *vena contracta* which is very near the aperture, and not to that of the fluid at the aperture itself. Therefore this velocity of projection is as the square root of the perpendicular altitude of the water above the centre of the orifice, (see p. 183.) ; whereas the velocity of the aperture itself is as the square root of half that altitude : and this seems to be sufficiently warranted by the result of experiments.

But when a pipe is adapted to the aperture, then the velocity of projection is not so great ; for in this case there is no contraction of the stream.

Independent of this circumstance, the velocity of projection, and the distance to which the jet can reach, are influenced by other circumstances; viz.  
1. By the friction against the sides of the pipe or aperture. 2. By the resistance of the air, in consequence of which the jet is obstructed throughout, and is divided at some unascertainable distance from the aperture: 3. By the weight of the fluid itself ; for when the highest particles of a perpendicular jet cease to have motion, as also in their descent, they press upon the ascending column.

From the friction against the sides of the pipe, and even of the edge of the aperture in a thin plate, various parts of the same jet acquire different velocities, but in virtue of the attraction of water to water, and of the lateral communication of motion

tion which arises therefrom, the whole jet presently acquires, and, for a certain length at least, proceeds with the same velocity in every part of a transverse section. But this velocity is a mean of the different velocities with which the various parts of the jet come out of the aperture; for whilst the filaments of greater celerity assist the motion of those which have a lesser celerity, the latter tend to retard the former: therefore it should seem that with a larger aperture, every thing else remaining the same, the velocity of projection must be greater than with a smaller aperture; and this is true to a certain degree. But then another circumstance interferes, which is the resistance of the air; for a larger jet, by presenting an ampler surface to the air, is liable to be divided by it, and by this division the surface is increased considerably, which renders the resistance of the air much greater; that resistance being, *ceteris paribus*, proportionate to the surface.

Now all those circumstances, namely, the friction against the sides of the aperture; the division of the stream, which increases not only according to the size of the jet, but likewise according to its initial velocity; and the resistance of the air, are so very fluctuating, that it is impossible to subject them to calculation.

Experience only can inform us of the effects which may be expected in certain circumstances: yet as the experiments can hardly ever be repeated

under the same circumstances precisely, the laws which are deduced from their general results, must always be admitted with some latitude.

If a vessel or reservoir of water be constructed somewhat like the representation of fig. 22. Pl. XII. and a hole be made in the thin side at A, the water which issues out of it will ascend in a perpendicular jet, enlarging and dividing itself towards the top; but it will not rise so high as the level of the surface B of the water in the vessel; and it will rise still less high, if a pipe be adapted to the aperture, as in fig. 23. or if a bent pipe proceed from a vessel, as in fig. 24. which is owing to the above-mentioned causes of obstruction; and in fact by removing those causes, at least in part, the height of the jet may be increased; observing however that it can never be made to equal the height of the water in the reservoir.

Thus, if the spout or aperture be inclined a little, viz. so as not to make the jet quite perpendicular, the water will ascend higher, because in this case the descending water will not press upon the ascending column.—If a pipe proceed from the vessel, as in fig. 24. then the pipe should be made large in proportion to the aperture, because in that case the water will move very slowly through the pipe, in proportion to what it does out of the aperture, and of course the friction will be much less than if the pipe and the aperture were both of the same diameter. It is also for the same reason that the jet will ascend higher when the conduit pipe is

short than when it is long ; and that the common figure of the pipes, from which the water spouts, which is that of a truncated cone of considerable length, will not let the jet ascend so high, nor be so uniform and transparent, as if a large tube were covered with a flat plate, and a smooth hole for the exit of the water were made in the middle of that plate.

By enlarging the aperture, the friction against the sides is diminished ; but the friction or opposition of the air is increased. Therefore as long as the former is diminished faster than the latter is increased, the jet may be made to ascend higher and higher by enlarging the aperture ; but beyond that limit the enlargement of the aperture will not increase the height of the jet. Now it has been found from a variety of experiments, that this limit, or maximum of effect, takes place when the diameter of the circular aperture is somewhat less than an inch and a quarter ; so that, *ceteris paribus*, the height of the jet will be less, when the aperture is either larger or narrower.

With a higher reservoir full of water, the perpendicular, or the nearly perpendicular, height of the jet is greater than with a lower reservoir ; but this also has a limit ; and it appears from a variety of experiments, that a jet cannot rise higher than about 100 feet, be the height of the water in the reservoir ever so great. For the higher the water is in the reservoir, the greater is the velocity at the aperture ;

aperture; and when that velocity has attained a certain degree, the great resistance of the air breaks the stream into small drops, which present a vast surface to the air, and are of course soon checked in their motion \*.

If a semicircle, as A D M B, fig. 25. Plate XII. be drawn upon the perpendicular side A B (as a diameter) of a vessel A K I B, which is kept constantly full of water; and if a hole be made in the thin side of the vessel, as at C; also a line, C D be drawn parallel to the horizon from the hole to the semicircle; then the fluid which issues from the hole C, will form a jet in the parabolic curve C E, and will fall upon the horizontal line B F, at a

\* A Table of the Heights to which jets of little more than an inch in diameter have been found to rise in a direction nearly perpendicular, when the altitudes of the water in the reservoirs are from five to 100 feet.

Res.	Jet.								
5	4,91	22	20,58	44	38,93	66	55,66	88	71,14
6	5,88	24	22,33	46	40,53	68	57,12	90	72,48
7	6,84	26	24,06	48	42,09	70	58,56	92	73,82
8	7,80	28	25,73	50	43,65	72	60,00	94	75,16
9	8,74	30	27,48	52	45,19	74	61,42	96	76,49
10	9,68	32	29,16	54	45,72	76	62,84	98	77,81
12	11,55	34	30,83	56	48,24	78	64,24	100	79,12
14	13,40	36	32,47	58	49,74	80	65,63		
16	15,22	38	34,11	60	51,24	82	67,02		
18	17,03	40	35,74	62	52,73	84	68,40		
20	18,82	42	37,35	64	54,20	86	69,76		

distance BE from the vessel, which is equal to twice the length of the line CD.—The distance Bl is called, as in solid projectiles, the *amplitude* of the jet.

This however must be understood for reservoirs or vessels of small heights, where the effect of the resistance of the air is inconsiderable; otherwise the deviation from the above-mentioned law is great and uncertain (3.)

It evidently follows, that when the hole is made at H, viz. in the middle of the altitude, then the amplitude BF, or the distance from the bottom B

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(3.) In Prop. I. of the note to the last Chapter of Part I. it has been demonstrated, that the velocity of a projectile in any point of the parabolic path, is the same as would be acquired by falling perpendicularly along a quarter of the parameter belonging to that point as a vertex. It has also been shown, that the fluid which comes out of the hole C, describes the parabola CE, and that its velocity at the *vena contracta*, which is very near the aperture, is the same as it would acquire by falling perpendicularly from A to C; therefore AC is the fourth part of the parameter which belongs to the vertex C of the parabola CE. One of the properties of the parabola is, that the square of the ordinate is equal to the product of the corresponding abscissas multiplied by the parameter; therefore  $\overline{BE}^2 = 4 \cdot \overline{AC}$ ; hence  $\overline{BE} = 2 \sqrt{\overline{AC} \times \overline{CB}}$ ; and  $\frac{1}{2} \overline{BE} = \sqrt{\overline{AC}}$ . But by the property of the circle (Eucl. p. 35. B.)  $\sqrt{\overline{AC} \times \overline{CB}} = \overline{CD}$ . Therefore  $\frac{1}{2} \overline{BE} = \overline{CD}$ . Reasoning is evidently applicable to any point in AB.

of the vessel, where the jet will strike the horizontal plane, is the greatest possible. Also that when a hole is made at an equal distance from the base, as at L, that another hole is from the top of the reservoir, as at C; the amplitudes will be equal, viz. the jets will strike the horizontal plane in the same point E; because in that case the line CD is equal to the line LM.

When the initial direction of the jet is neither perpendicular nor parallel, but oblique, to the horizon, then its parabolic path differs in altitude, &c., according to the angle of inclination. But the various particulars which belong to it may be determined from the theory of projectiles, which has been delivered in the last chapter of the first part of these elements; observing however that those theoretical results are nearly true for short distances only; but that when the distances, size of the jet, &c. are more considerable, then nothing but actual experiments can determine the result\*.

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\* For farther particulars relative to the subject of this chapter, see s'Gravesande's Nat. Phil.; Bossut's Hydrodyn.; De Prony's Architect. Hydraulique; Venturi on the lateral communication of motion in fluids; Vince's hydrostatics, &c. as also most of the other works which are mentioned in the note, p. 113. at the end of chap. IV.

## CHAPTER VIII.

OF PNEUMATICS, OR PERMANENTLY ELASTIC FLUIDS; OF THE ATMOSPHERICAL AIR; AND OF THE BAROMETER.

THE whole globe of the earth is surrounded by, or is involved in, a fluid, called *air*, which though not perceived by our eyes, is, however, manifested in various ways. This fluid fills up the space from the surface of the earth to the height of several miles above it, and the whole mass of it is called the *atmosphere*.

As fishes are surrounded by water, and live and move in water, so are we human beings, and all other animals, surrounded by air, and live and move in air.

A fish which is taken out of the water, will die in a short time, and a human being, or any animal taken out of the aerial fluid, will in general die much sooner.

Water gravitates towards the centre of the earth, and so does the air\*. Hence, as a fish or other body in water is pressed on every side by that fluid, so are other animals, &c. pressed on every side by the sur-

\* The pressure of the air was first asserted by the Great Galileus, and was soon after illustrated by his scholar Torricellius.

ounding air, and this pressure (as will be shewn in the sequel) is very considerable.

As the progressive motion of water from one place towards another, is called a *current* of water; so the progressive motion of the atmospherical air is called in general *wind*, which according to the different velocities of that fluid is more particularly specified by the appellations of *breeze*, *gentle wind*, *gale*, &c.

But the particulars in which air principally differs from water, are 1st, that air weighs a vast deal less than water; and 2dly, that water is not compressible, whereas a quantity of air may be forced into a smaller space, by means of pressure, or it may be expanded by removing the pressure; and that expansibility, as far as we know, may be extended to any degree; nor is it diminished by long continued pressure.

Air is absolutely necessary to animal life, as also to combustion, to vegetation, and to other natural processes. In all those processes the air either communicates something to the substances concerned, or it receives something from them. But this property of receiving or giving is limited; for instance, a certain quantity of air is necessary for the life of an animal during a given time; now when the animal has lived in it that length of time, the same quantity of air will be unfit for the support of the life of that or of any other animal. And the same thing must

be understood, with respect to combustion and several other processes.

Those latter properties of the air are called its *chemical properties*, which will be explained when we come to treat of chemistry; whereas its other properties, such as its gravity, compressibility, &c. are called its *mechanical properties*, and these will be examined in the present chapter.

I shall just mention for the present, that besides the atmospherical air, which surrounds the earth, there are other permanently elastic fluids, the chemical properties of which are essentially different from those of air; though their mechanical properties are similar to those of that atmospherical fluid; on which account they are all comprehended under the general appellation of *aërial fluids*, or of *permanently elastic fluids*; which expression means, that, as far as we know, they are not convertible into a visible fluid by means either of pressure or of cold; and thence they are distinguished from vapours, as from the vapour or *steam* of water, which is likewise an elastic fluid, but not permanently so; for either by cooling, or by means of pressure, that vapour is converted into water.

The principal mechanical properties of air are its weight and elasticity; but let us begin by manifesting its existence.

When a person blows upon a thread, or dust, or other light bodies that are placed at a short distance from

from his mouth, the light bodies are driven away from their places. Now it is the current of air, that being expelled from the lungs through the mouth, drives the light bodies in its way.

Take a glass vessel, such as a common wine glass, turn it upside down, and holding it in that perpendicular position, immerse it in water, as at A, fig. 1. Plate XIII. it will be found that the water does not enter the glass.—That substance which thus prevents the entrance of the water into the cavity of the glass, is a quantity of air. If you incline the glass a little, a bubble, viz. a certain quantity of air goes out, and an equal bulk of water takes its place. If the glass be inclined still more, all the air will escape from it, and the glass will be entirely filled with water.—The various parts of this experiment may be explained in a more particular manner; thus, when the glass is in the situation A, the air in it, being the lighter fluid, is confined by the water which occupies the aperture of the glass; but the air being compressible, the pressure of the superincumbent water A B, (p. 31.) forces the air into a narrower space; hence the water will be seen to ascend a little way within the glass at B, and the lower you immerse the glass, the higher will the water ascend within it. When the glass is inclined, as at D, the surface of the water in it, which remains always horizontal, is *d'e*, (p. 28.) and the air occupies the space *c*, the lower part of which is even with the edge *d* of the glass. If the glass be inclined

inclined a little more, part of the air is forced out, as is shown at M.

The quantity of air which thus escapes from the cavity of the glass, being pressed on every side by the water, is forced to assume a globular form, in which shape it is called a *bubble*, which being lighter than an equal bulk of water, ascends to the surface of the latter, where it mixes with the common mass of atmospherical air.

But frequently, when the bubble is small, it remains for a certain time on the surface of the water, enclosed in a film or shell of water; which is owing to the viscosity of the water, or to the attraction mutual between the particles of water. In fact, whatever increases that viscosity, such as a solution of soap, which is frequently practised by children, or of any other glutinous matter, will increase the durability of the bubbles, and in that case, by blowing into the solution, the bubbles may be made very large \*.

Hence it appears that a bubble of air is not, according to the vulgar idea, an empty space, a mere nothing; but that it consists of a fluid, which,

\* Distillers and other persons that have occasion to try specimens of spirituous liquors, can form a tolerably accurate idea of the strength of those liquors, by shaking the bottle, and then observing how soon the bubbles break on the surface of the liquor; for the thinner and purer the spirit is, the sooner will the bubbles break.

though

though invisible, has however weight and other qualities; and is, in short, a substance as much as any other substance which we feel or taste \*.

When by inclining the above-mentioned glass sufficiently in water, all the air is suffered to escape from it; then if this glass be again turned with its aperture downwards, and in that position be drawn upwards, until its aperture remains a little below the

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\* The invisibility of air is what suggests the vulgar idea of its being nothing. But it must be considered, that transparent bodies, viz. such as let the rays of light pass freely through them, cannot be seen. Thus water, glass, air, &c. cannot be perceived by an eye which is entirely surrounded by any one of them. And even when that is not the case, we can only perceive those substances by the heterogeneous bodies which they may happen to contain, or by the inflection, refraction, &c. of the rays of light at their surfaces; hence, when such bodies are pure, and their surfaces are removed from our sight, so that we cannot observe the bending of the rays of light at those surfaces, then it is impossible to discern the bodies themselves.—If a glass bottle entirely filled with pure water, be situated against a dark place, so that no objects may be seen through it, a person who looks directly at it will not be able to say whether the bottle be full of water or not.

A fish or a man in water, will feel the water, but he cannot see it.

The particles which are seen moving about when light passes through a hole in a room otherwise dark, are not the particles of air, but they are particles of dust, &c. which float in the air.

surface

surface of the water in the basin, as at N, the glass will remain entirely full of water; the pressure of the atmosphere on the surface of the water of the basin forcing or keeping up the water which fills the glass. Nor, in this case, can any air enter the cavity of the glass, because air being specifically lighter than water, cannot possibly descend from  $d$  to  $e$ , in order to enter that cavity. But if the glass be raised higher still, so that its aperture be elevated above the surface of the water in the basin, then the air will immediately enter on one side of the aperture, whilst the water goes out at the opposite side.

When the vessel is short, and its aperture less than a quarter of an inch in diameter, the water or other fluid will not easily run out of it, though the vessel be situated with the aperture downwards. This is owing to the attraction of aggregation between the particles of water; which will not suffer the small quantity of liquor in the neck of the vessel to be divided so as to give room for the entrance of the air: hence it appears why phials with small necks are difficultly filled with any liquor, and difficultly emptied.

A well known experiment, which is frequently shewn in a familiar way, depends upon the above-mentioned principle.—A wine glass is entirely filled with water or wine; then a flat piece of paper is placed over it, and the palm of the hand is put over the paper. Things being thus prepared, the glass with

with the hand, &c. is turned upside down, then the hand being gently removed, the glass will be found to remain full of water, with the paper adhering to it.

The following experiment is intended to shew the same property; namely, the pressure of the atmosphere in a different and perhaps more satisfactory way.

Take a glass tube of a pretty uniform bore, and open at both ends, as A B, fig. 2. Plate XIII. fit a cork *d* B to it, and let a stick or wire *E d*, be firmly cemented into the cork. In short, form a piston, like that of a syringe, to the glass tube. Now place this piston even with the lower end of the tube, as represented at B, in the figure, and in that situation place the same end of the tube in water, as in fig. 3. and holding the tube steadily, pull up the piston gradually. It will be found that the water follows the cork, and fills up all that part of the tube which is below the piston, as is shewn in fig. 3. By this means the pressure of the atmosphere is removed from over that part of the water which is immediately under the tube; therefore the pressure of the atmosphere on the rest of the surface of the water in the basin, forces that water into the tube, filling up its cavity as far as the piston.

But this pressure is limited; for if the tube be longer than 33 or 34 feet, and the piston be pulled up to the highest part of it, the water will not rise higher than about 33 feet, and the rest of the tube

has been called a *barometer* or *baroscope*, viz. from its property of shewing the actual weight of the atmosphere at any particular place and time\*.

No period or regularity has been as yet discovered with respect to this change of gravity, or to the rise and fall of the mercury in the barometer, which is equivalent to that pressure; so that it is impossible to foretel the altitude of the quicksilver in the barometer for any particular time. But it has been observed, that the altitudes of the mercury in the barometer are frequently accompanied with certain states of the weather, such as wind, rain, calms, storms, &c. and frequently also a certain altitude of the barometer precedes that particular state of the weather which is usually connected with it, on which account barometers are often called *weather glasses*, and are commonly kept in houses, on board of ships, &c. as indicators of the weather.

The principle upon which those barometers are constructed, has already been explained; the other parts which are annexed to the common construction, are either ornamental, or they are intended for the security of the tube; of the quicksilver in

\* This suspension of the quicksilver in the barometer, or inverted glass tube, not beyond a certain altitude, and the variations of that altitude, were first observed by the celebrated Italian philosopher Torricelli; hence the barometer is often called the *Torricellian tube*; and the vacuum in the upper part of it, is called the *Torricellian vacuum*.

Bason, &c. they will be particularly described after. The words which are engraven on the of inches and tenths, which is annexed to the ble part of the altitude, are expressive of the her, which has been observed frequently to mpany those particular altitudes of the mercury. y are as follows:

*Inches.*                    *Words annexed.*

31.	Very dry. Hard frost.
30,5.	Settled fair. Settled frost.
30.	Fair. Frost.
29,5.	Changeable.
29.	Rain. Snow.
28,5.	Much rain. Much snow.
28.	Stormy weather.

the rising and falling of the mercury in the barometer must not be considered as sure indications of the weather which is to follow; yet in general it will enable the observer to form a pretty good idea of the change of weather which may be expected. Numerous observations relative to this subject have been made in various parts of the world, and, from a collection of those observations, Dr. Halley deduced a set of rules, which were published in an early volume of the Philosophical Transactions, and to which not much attention has been made by subsequent observers.

I shall now subjoin those rules, or natural laws, together with the conjectures relative to the causes upon which they depend, in Dr. Halley's own words.

" To account for the different heights of the mercury at several times, it will not be unnecessary to enumerate some of the principal observations made upon the barometer.

" 1. The first is, that in calm weather, when the air is inclined to rain, the mercury is commonly low.

" 2. That in serene, good, settled weather, the mercury is generally high.

" 3. That upon very great winds, though they be not accompanied with rain, the mercury sinks lowest of all, with relation to the point of the compass the wind blows upon.

" 4. That, *cæteris paribus*, the greatest heights of the mercury are found upon easterly and north-easterly winds.

" 5. That in calm frosty weather, the mercury generally stands high.

" 6. That after very great storms of wind, when the quicksilver has been low, it generally rises again very fast.

" 7. That the more northerly places have greater alterations of the baroscope than the more southerly.

" 8. That within the tropics, and near them, those accounts we have had from others, and my

own

own observations at St. Helena, make very little or no variation of the height of the mercury in all weathers.

" Hence I conceive that the principal cause of the rise and fall of the mercury, is from the variable winds which are found in the temperate zones, and whose great inconstancy here in England is most notorious.

" A second cause is the uncertain exhalation and precipitation of the vapours lodging in the air, whereby it comes to be at one time much more crowded than at another, and consequently heavier ; but this latter in a great measure depends upon the former. Now from these principles I shall endeavour to explicate the several phænomena of the barometer, taking them in the same order I laid them down.

" 1. The mercury's being low, inclines it to rain, because the air being light, the vapours are no longer supported thereby, being become specifically heavier than the medium wherein they floated ; so that they descend towards the earth ; and, in their fall, meeting with other aqueous particles, they incorporate together, and form little drops of rain. But the mercury's being at one time lower than at another, is the effect of two contrary winds blowing from the place where the barometer stands, whereby the air of that place is carried both ways from it, and consequently the incumbent cylinder of air is diminished, and accordingly the mercury sinks. As

for instance, if in the German ocean it should blow a gale of westerly wind, and at the same time an easterly wind in the Irish sea, or if in France it should blow a northerly wind, and in Scotland a southerly, it must be granted me that that part of the atmosphere impendent over England would thereby be exhausted and attenuated, and the mercury would subside, and the vapours, which before floated in those parts of the air of equal gravity with themselves, would sink to the earth.

" 2. The greater height of the barometer is occasioned by two contrary winds blowing towards the place of observation, whereby the air of other places is brought thither and accumulated; so that the incumbent cylinder of air being increased both in height and weight, the mercury pressed thereby must needs rise and stand high, as long as the winds continue so to blow; and then the air being specifically heavier, the vapours are better kept suspended, so that they have no inclination to precipitate and fall down in drops; which is the reason of the serene good weather which attends the greater heights of the mercury.

" 3. The mercury sinks the lowest of all by the very rapid motion of the air in storms of wind: for the tract or region of the earth's surface, wherein these winds rage, not extending all round the globe, that stagnant air which is left behind, as likewise that on the sides, cannot come in so fast as to supply the evacuation made by so swift a current; so

that

that the air must necessarily be attenuated when and where the said winds continue to blow, and that more or less, according to their violence ; add to which, that the horizontal motion of the air being so quick as it is, may in all probability take off some part of the perpendicular pressure thereof, and the great agitation of its particles is the reason why the vapours are dissipated, and do not condense into drops so as to form rain ; otherwise the natural consequence of the air's rarefaction.

" 4. The mercury stands the highest upon an easterly or north-easterly wind, because in the great Atlantic ocean, on this side the 35<sup>th</sup> degree of north latitude, the westerly and south-westerly winds blow almost always trade ; so that whenever here the wind comes up at east and north-east, it is sure to be checked by a contrary gale as soon as it reaches the ocean ; wherefore, according to what is made out in our second remark, the air must needs be heaped over this island, and consequently the mercury must stand high, as often as these winds blow. This holds true in this country, but is not a general rule for others, where the winds are under different circumstances ; and I have sometimes seen the mercury as low as 29 inches upon an easterly wind, but then it blew exceeding hard, and so comes to be accounted for by what was observed upon the third remark.

" 5. In calm frosty weather, the mercury generally stands high, because (as I conceive) it seldom

freezes but when the winds come out of the northern and north-eastern quarters ; or at least unless those winds blow at no great distance off; for the northern parts of Germany, Denmark, Sweden, Norway, and all that tract from whence north-eastern winds come, are subject to almost continual frost all the winter ; and thereby the lower air is very much condensed, and in that state is brought hitherwards by those winds ; and being accumulated by the opposition of the westerly wind blowing in the ocean, the mercury must needs be prest to a more than ordinary height ; and as a concurring cause, the shrinking of the lower parts of the air into lesser room by cold, must needs cause a descent of the upper parts of the atmosphere, to reduce the cavity made by this contraction to an *æquilibrium*.

“ 6. After great storms of wind, when the mercury has been very low, it generally rises again very fast. I once observed it to rise  $4\frac{1}{2}$  inch in less than six hours, after a long continued storm of south-west wind. The reason is, because the air being very much rarefied by the great evacuations which such continued storms make thereof, the neighbouring air runs in the more swiftly to bring it to an *æquilibrium* ; as we see water runs the faster for having a great declivity.

“ 7. The variations are greater in the more northerly places, as at Stockholm greater than at Paris (compared by Mr. Pascall \*) ; because the

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\* *Equilibre des Liqueurs.*

more

more northerly parts have usually greater storms of wind than the more southerly, whereby the mercury should sink lower in that extremum; and then the northerly winds bringing the condensed and ponderous air from the neighbourhood of the pole, and that again being checked by a southerly wind at no great distance, and so heaped, must of necessity make the mercury in such case stand higher in the other extremum.

" 8. Lastly, this remark, that there is little or no variation near the equinoctial, as at Barbadoes and St. Helena, does above all others confirm the hypothesis of the variable winds being the cause of these variations of the height of the mercury; for in the places above-named, there is always an easy gale of wind blowing nearly upon the same point, viz. E. N. E. at Barbadoes, and E. S. E. at St. Helena, so that there being no contrary currents of the air to exhaust or accumulate it, the atmosphere continues much in the same state: however, upon hurricanes (the most violent storms) the mercury has been observed very low, but this is but once in two or three years, and it soon recovers its settled state of about  $29\frac{1}{2}$  inches.

" The principal objection against this doctrine is, that I suppose the air sometimes to move from those parts where it is already evacuated below the equilibrium, and sometimes again towards those parts where it is condensed and crowded above the mean state, which may be thought contradictory to

the law of statics, and the rules of the *equilibrium* of fluids. But those that shall consider how, when once an *impetus* is given to a fluid body, it is capable of mounting above its level, and checking others that have a contrary tendency to descend by their own gravity, will no longer regard this as a material obstacle; but will rather conclude, that the great analogy there is between the rising and falling of the water upon the flux and reflux of the sea, and this of accumulating and extenuating the air, is a great argument for the truth of this hypothesis. For as the sea over against the coast of Essex rises and swells by the meeting of the two contrary tides of flood, whereof the one comes from the S. W. along the channel of England, and the other from the north, and on the contrary sinks below its level upon the retreat of the water both ways, in the tide of ebb; so it is very probable, that the air may ebb and flow after the same manner; but by reason of the diversity of causes, whereby the air may be set in moving, the times of these fluxes and refluxes thereof are purely casual, and not reducible to any rule, as are the motions of the sea, depending wholly upon the regular course of the moon." So far are Dr. Halley's observations.

" It is," says Col. Roy, " a well known and established fact, that, in the middle latitudes, a north or north-east wind constantly raises the barometer, and generally higher as its continuance is longer. The contrary happens when a south or south-

South-west wind blows; for I believe it is commonly lowest when the duration and strength of the wind from that quarter have been the greatest. Thus the north-east wind, by blowing for any length of time, brings into the middle latitudes a mass of air heavier than that which naturally appertains to the region, and raises the barometer above its mean height. The continuance of a south-western carries off the heavy air, deposits a much lighter body in its stead, and never fails to sink the barometer below its mean height."

The greatest alterations of the barometer generally take place during clear weather, with a northerly wind; the small changes generally take place during cloudy, rainy, or windy weather, with a southerly wind. The changes of the barometrical altitude are greater in winter than in summer; but the mean elevation is greater in summer than in winter, and greatest at the equinox.

The barometer is generally lower at noon and at midnight, than at any other period of the 24 hours.

To those we may add De Luc's observation, viz. that a rapid movement of the mercury in the barometer, even when rising, is an indication of bad weather, but not of long duration.

Such are the indications which may be derived from the movements of the barometer alone; but the observers of later times, having made a rational investigation of the possible influence of the moon

upon the atmosphere, and upon the weather, have shewn that we may form much more probable conjectures relative to the weather, by combining the observations of the barometrical movements with the situations of the moon \*. But of this more in the next chapter.

The movement of the mercury in the barometer about our latitude, has been already said to amount to about 3 inches. But it will be of use to know its more ordinary altitude, or its mean altitude.

It appears from the meteorological journals of the Royal Society, which are published annually in the Philosophical Transactions, that the mean altitude of the barometer is 29,89 inches, and the mean altitude of the barometer for each single year, hardly ever differs from the above, by more than half a tenth of an inch; as appears from the following statement of the mean barometrical altitude of each year, commencing with the year 1787, from which time the barometrical observations at the apartments of the Royal Society have been made with great attention and regularity †.

1787.	29,80	1792.	29,87	1797.	29,92
1788.	29,96	1793.	29,93	1798.	29,92
1789.	29,79	1794.	29,91	1799.	29,84
1790.	29,98	1795.	29,90	1800.	29,90
1791.	29,87	1796.	29,89		

The

\* See Toaldo's System respecting the probability of a change of weather, &c. in the *Journal des Sciences Utiles*.

† The mercury in the basin of the barometer of the Royal

The French reckon the mean altitude of the mercury in the barometer placed on the level of the sea, equal to 28 French inches, which are equivalent to 29,841 inches English\*.

It appears very clearly, from what has been already said in this chapter, that the air is a ponderous substance; but the particular weight of a given quantity of air, or its specific gravity, is ascertained by actually weighing it with a balance. For this purpose a glass vessel is weighed first full of air, then exhausted of air, and lastly, full of water, by which means we obtain the weights of equal bulks of air and of water; and dividing the former by the latter, the quotient will express the specific gravity of the air †. But it must be observed, that air, being very elastic, its bulk, and consequently its specific gravity, is easily increased or diminished by heat and cold, as also by an alteration of the pressure; therefore, whenever the specific gravity of an aerial fluid is to be stated, it is always proper to set down the altitude of the mercury in the barometer, and the degree of heat, at

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Royal Society at Somerset House, is situated 81 feet above the river Thames, viz. the level of low water spring tides. The observations are taken twice a day, viz. at 7 or 8 in the morning, and at 2 in the afternoon. The mean for the whole year is obtained by adding all the observations together, and dividing the sum by the number of observations.

\* De Prony's Architecture Hydraulique, p. 298.

† The construction of the vessel fit for this purpose, as also the manner of exhausting it, will be described hereafter,

the time of weighing the air. And this precaution has been observed in the table of specific gravities. See p. 95.

The knowledge of the pressure of the atmosphere, and of the perpendicular pillar of quicksilver, which is equivalent to it, enables us to calculate the actual pressure of the atmosphere upon the whole globe of the earth, upon the human body, or upon any other body; and it appears that this pressure is prodigiously great, yet we do not find it incommodious or oppressive, because we are pressed on every side by it, and the pressure on the surface of our bodies is counteracted by the fluids and solids of our bodies, which are almost entirely non elastic. If that pressure be removed from one side, then it will be found to act with prodigious force on the other side.

As the pressure of the atmosphere supports a perpendicular pillar of quicksilver between 28 and 31 inches high, the weight of such a pillar, let its base be what it may, shews the pressure of the atmosphere upon a surface equal to that base. Now a pillar of quicksilver, whose base is an inch square, and whose altitude is 28 or 31 inches long, weighs 13,75, or 15,23 pounds avoirdupoise, the mean of which is 14,49 pounds; therefore at a mean the pressure of the atmosphere upon every square inch, at the surface of the earth, is about  $14\frac{1}{2}$  pounds avoirdupoise; then by the rule of proportion, or simply by multiplication, we may easily find out the pressure upon any given surface. Thus the pressure of the atmospher

atmosphere on a square foot, (which contains 144 square inches) is equal to 144 times 14  $\frac{1}{2}$  pounds, viz. to 2088-pounds. The pressure of the atmosphere on the body of a middle sized human being reckoning its surface equal to 12 square feet) is 12 times 2088.; that is 25056 pounds, or upwards of eleven tons. The pressure on the surface of the whole earth (which, in round numbers, is equal to 557568000000000 square feet,) is equal to about 1164201984000000000 pounds.

It is now necessary to examine the elastic property of air.

If from a vessel full of water, part of the water be removed, then the cavity of that vessel will not be entirely occupied by water. Now the same thing cannot be done with air; for if from a vessel full of air, half the air be removed by means of a proper engine, and the entrance of other air be prevented, the vessel will still remain entirely full of air, only the air in it will be half as dense as it was before. If, instead of the half, you remove a much greater portion of the air from the above-mentioned vessel, the vessel will still remain entirely full of air; only the air in it will be proportionately less dense. In short, by removing the pressure, a quantity of air may always be expanded; nor is it known to what degree this expansion will reach; consequently it is not in our power to determine the extent of the atmosphere.

On the other hand, by increasing the pressure proportionately,

portionately, a quantity of air may be condensed into any given space, however small ; the density of the compressed air increasing according as the bulk is diminished. Nor has this condensation any known limits, though it seems rational to suppose that a limit it must undoubtedly have.

If a glass vessel full of air be immersed in water with its aperture downwards, the water immediately under it, which at first lies even with its aperture, will gradually rise in the vessel in proportion as the vessel is conveyed deeper and deeper into the water ; the air in it being compressed and condensed by the perpendicular altitude of the superincumbent water. On drawing the vessel upwards, the air in it will expand again.

This experiment shews that air is compressible ; but the following experiment will shew that the bulk of a given quantity of air is inversely (and of course its density is directly) as the compressing force ; for instance, if a certain weight compresses a quantity of air into the half of its original bulk, twice that weight will compress it into a quarter of its original bulk ; ten times that weight will force it into the 20<sup>th</sup> part of its original bulk ; and so on.

Take a cylindrical glass tube bent in the form of ABCD, fig. 4. Plate XIII. open at A, and closed at D, and place it with the bent part downwards ; pour as much quicksilver into the aperture A, as will barely fill the horizontal part BC, which will confine the air in DC. This air, like the air

which

which is about the apparatus, &c. is compressed by the usual pressure of the atmosphere, and this pressure is represented by (since it is equivalent to) the actual altitude of the mercury in the barometer. Now, if you pour more quicksilver into the aperture A, the air in CD will thereby be compressed into a narrower space; as is indicated by the mercury rising into the part CD, and it will be found, that the space De, in which the air has been contracted by the pressure of the perpendicular pillar of mercury gf, (the altitude of which must always be reckoned from the level of the surface eg of the mercury in the part CD) in addition to the usual pressure of the atmosphere, is to its original bulk CD, as the usual pressure of the atmosphere (or as the actual altitude of the barometer) is to the sum of that actual altitude, and the altitude gf. Thus when gf is equal to the actual altitude of the mercury in the barometer, then the pressure on the confined air is twice as great as if it were pressed by the atmosphere only; therefore that air will be confined into the half of its original bulk, viz. De will be the half of DC. When the altitude gf is made equal to twice the altitude of the mercury in the barometer, then the pressure on the confined air will be three times as great as if it were pressed by the atmosphere only; hence De will be found equal to a third part of DC; and so on.

The expansion of air in proportion to the diminution of the pressure, may be shewn by a variety of experiments.

experiments. We shall for the present, however, describe only one which may be easily performed.

Take a cylindrical glass tube, closed at one end and open at the other, fill it with quicksilver to a certain height, and leave the rest full of air (or, as it would commonly be expressed, leave it empty); put a finger upon the aperture of the tube; turn the tube with the aperture downwards; immerse that aperture together with the finger, in a basin of quicksilver, then remove the finger; and it will be found that the air which was left into the tube, and which now occupies the upper, that is the closed, part of the tube, has enlarged its dimensions. Suppose, for instance, that the tube be 30 inches long, that it be filled with mercury, excepting 8 inches. When the tube is inverted, as in fig. 5. Plate XIII. the air will occupy the upper part AB, and the mercury the lower part BC; but the part AB, which is occupied by the air, will be found to be longer than 8 inches; the reason of which is, that the original quantity, viz. 8 inches of air, which before the tube was inverted, was pressed by the atmosphere, now sustains a lower degree of pressure; that is, the pressure of the atmosphere is partly counteracted by the pillar of mercury BC. Therefore, since the bulks of the same quantity of air are inversely as the pressures, it will always be found that the difference of the actual altitude of the mercury in the barometer, and the altitude BC of the mercury in the above-mentioned tube, is to

the

the actual altitude of the mercury in the barometer, is 8 inches (viz. the original bulk of the confined air) is to its present bulk AB; so that if the actual altitude of the mercury in the barometer be 28 inches, CB will be found equal to 14 inches, and AB equal to 16 inches; for in that case  $28 - 14$  (viz. 14) : 28 :: 8 : 16.

Air has been left for several years very much compressed in proper vessels, wherein there was nothing that could have a chemical action upon it; and afterwards on removing the unusual pressure, and replacing it in the same temperature, the air has been found to recover its original bulk, which proves that the continuance of the pressure had not diminished the elasticity of it in the least perceptible degree.

## CHAPTER IX.

OF THE DENSITY AND ALTITUDE OF THE ATMOSPHERE, TOGETHER WITH THE METHOD OF MEASURING ALTITUDES BY MEANS OF BAROMETRICAL OBSERVATIONS.

EXPERIENCE shews that the atmosphere, or the air, which surrounds the earth, is of different densities at different distances from the centre thereof. Our direct experiments, however, do not reach to any great heights into the regions of the atmosphere. But the numerous experiments, which have been made on the compression of air, the most convincing of which have already been mentioned, prove that air is condensed in proportion to the force which compresses it, or that it expands in the inverse ratio of that force, and that it does not lose any portion of its elasticity by remaining long confined. We are, therefore, authorised to suppose that the air, at all distances from the earth, is more or less dense, according as it is situated nearer to, or farther from, it; or according as it is pressed by a greater or lesser weight of superincumbent air. We may also conclude, that, not knowing how far air may be expanded, we cannot determine to what height the atmosphere is extended.

But

But the compression arising from the weight of the superincumbent air, though by far the principal, is not the only cause upon which the various density of the atmosphere depends. In short, all the causes, which seem to concur towards the production of that effect, are, 1. The various quantity of superincumbent air at different altitudes; 2. The decreasing attraction of the earth, or the decreasing weight of bodies, in proportion to the squares of the distances from the centre of the earth; 3. The influence of heat and cold; 4. The admixture of vapours and other fluids; and, 5. The attraction of the moon and other celestial bodies.

For the sake of perspicuity, we shall examine each of those causes successively, and in the first place we shall endeavour to explain the effects of pressure.

Imagine that A B C D, fig. 6, Plate XIII. is a pillar, or vessel, full of air, reaching from the surface A B of the earth, to the farthest part C D of the atmosphere; for whatever is proved with respect to the density of the air in this pillar, or portion of the atmosphere, will evidently stand good with respect to any other contiguous pillar or portion of it, and, of course, with respect to the whole atmosphere.

Imagine likewise, that this pillar is divided by partitions parallel to the horizon, into a vast number of equal spaces, A B e f, e f g b, g b i k, i k m n, &c.

Now as the density of the air is continually decreasing from the earth upwards ; therefore, strictly speaking, that density must be various, even in different parts of every one of those spaces : yet as those spaces may be conceived to be infinitely small, we may, without any sensible error, suppose that the density of the air is uniform throughout the various parts of any one of them.

Since the density of the air is always as the force which compresses it ; and since the air in every part of the atmosphere is pressed by the weight of the superincumbent air ; it follows that the density of the air in  $A B e f$ , is to the density of the air in  $e f g b$ , as  $e f C D$  is to  $g b C D$ . So that the difference between the pressures on  $ef$  and on  $gb$  (or between the quantities of air  $A B e f$ , and  $e f g b$ ,) is equal to the quantity of air  $e f g b$ . For the same reason, the difference between the pressures on  $gb$  and on  $ik$  (or between the quantities of air in  $e f g b$  and  $g b i k$ ) is equal to the quantity of air  $g b i k$ . Also the difference between the pressures on  $ik$  and on  $mn$  (or between the quantities of air  $g b i k$  and  $i k m n$ ) is equal to the quantity of air  $i k m n$  ; and so on. Therefore the quantities of air, or the densities of air, in those spaces, are proportional to the quantities of which they themselves are the differences. But when there is a series of quantities, whose terms are proportional to their own differences, then both those quantities and their differences,

differences, are in geometrical progression\* ; therefore the densities, or quantities, of air in the equal spaces  $ABe f$ ,  $cfgb$ ,  $gbik$ ,  $ikmn$ , &c. are in geometrical progression.

It must likewise be observed, that the heights of those equal spaces above the surface  $AB$  of the earth, are in arithmetical progression ; viz. if the second space be one inch above the surface, the next will be two inches above that surface, the next to that will be three inches, and so on ; or instead of inches their altitudes may be of any other dimension, as the one-hundredth, or the one-thousandth part of an inch. From all which we derive a very remarkable conclusion ; namely, *that if the altitudes above the surface of the earth be taken in arithmetical progression, the densities of the air at those altitudes will be in geometrical progression decreasing.*

Thus, for instance, if at a certain altitude the air be half as dense as it is immediately on the surface of the earth ; then at twice that altitude, the air will be four times less dense than upon the surface of the earth ; at three times that altitude, it will be eight times less dense ; and so forth.

Experience, assisted by calculation, shews that at a distance of seven miles from the surface of the earth, the air is about four times less dense than it is

Let  $A, B, C, D, \dots$  be a series of quantities, and if the differences be proportional to their own quantities, we have  $\lambda : A - B :: B : B - C :: C : C - D, \dots$  Conversely (Eucl. Cor. to Prop. 19. B. v.)  $A : B :: C : D, \dots$

close to that surface\*. Now the knowledge of this fact will enable us to construct a table of densities (or of pressures) of the atmosphere at all altitudes from the surface of the earth ; which may be done in the following manner :

Take the altitudes in arithmetical progression, viz. 7 miles, 14, 21, 28, 35, &c. Then for the densities, say, by the rule of three, as 1 is to  $\frac{1}{2}$ , so is  $\frac{1}{2}$  to a fourth proportional, which is  $\frac{1}{16}$ , and shews, that at the height of 14 miles the density of the atmosphere is the 16th part of what it is close to the surface of the earth. Again, say, as  $\frac{1}{2}$  is to  $\frac{1}{16}$ , so is  $\frac{1}{16}$  to a fourth proportional, which is  $\frac{1}{256}$ , and shews, that at the distance of 21 miles the density of the atmosphere is the 64th part of what it is close to the surface, &c. Thus you have the densities (or the pressures which are as the densities) of the atmosphere at the undermentioned distances.

Altitudes in miles.	Correspondent densities.
0	1
7	$\frac{1}{2}$
14	$\frac{1}{16}$
21	$\frac{1}{256}$
28	$\frac{1}{2304}$
35	$\frac{1}{18432}$
42	$\frac{1}{15360}$
49	$\frac{1}{12384}$
56	$\frac{1}{9336}$
&c.	&c.

\* Cotes's Hyd. Lectures, Lect. IX.

Then,

Then, in order to find the densities correspondent to the intermediate altitudes, take an arithmetical mean proportional between 7 miles and 14 miles, which is  $10\frac{1}{2}$  miles \* ; also, take a geometrical mean proportional between the densities of the air at 7, and at 14 miles, viz. between  $\frac{1}{4}$  and  $\frac{1}{16}$ , which is  $\frac{1}{8}$  † ; and this is the density of the air at the altitude of  $10\frac{1}{2}$  miles. Again, take an arithmetical mean proportional between 14 and 21 miles, which is  $17\frac{1}{2}$  miles ; also, take a geometrical mean proportional between the densities of the air at the above-mentioned two altitudes, viz. between  $\frac{1}{16}$  and  $\frac{1}{24}$ , which is  $\frac{1}{32}$ , and it expresses the density of the air at the height of  $17\frac{1}{2}$  miles. After the same manner you may take an arithmetical mean proportional between  $17\frac{1}{2}$  and 21 miles, and a geometrical mean proportional between the densities at those altitudes. In short, the like operation may be performed with any two altitudes, and their correspondent densities ; by which means a table of densities,

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\* An arithmetical mean proportional between two numbers is found by taking the half of the sum of the two numbers. Thus the sum of 7 and 14 is 21, the half of which is  $10\frac{1}{2}$ .

† A geometrical mean proportional between two numbers, is found by extracting the square-root of the product of the two numbers. Thus  $\frac{1}{4}$  multiplied by  $\frac{1}{16}$ , gives  $\frac{1}{16}$ , the square root of which is  $\frac{1}{8}$ ; and  $\frac{1}{8}$  is the geometrical mean between  $\frac{1}{4}$  and  $\frac{1}{16}$ .

answering to certain altitudes, may be constructed. This laborious operation, however, may be avoided; for the same thing may be obtained by using a table of logarithms, which logarithms in fact are a set of numbers in arithmetical progression, annexed to another set of numbers, which are in geometrical progression; so that the former may represent the altitudes, whilst the latter represent the densities of the atmosphere correspondent with those altitudes.

The principal use of such a table is for measuring perpendicular altitudes above the surface of the earth, by means of barometrical observations, the principle of which operation we shall endeavour to explain.

The barometer, as has been shewn in the preceding chapter, shews the actual pressure of the atmosphere, or the density of the air at the place where it is situated; therefore the altitude of the mercury in a barometer, placed at the top of a mountain, will not be so great as the altitude of the mercury in a barometer placed on the sea shore. Now those altitudes of the mercury being as the densities, and the density at the surface of the earth, or on the sea shore, being called one in the table, we say, as the barometrical altitude at the surface is to the barometrical altitude on the mountain, so is one to the density of the air at the top of the mountain; and finding the density thus obtained in the table, we have against it the correspondent altitude, or the

the perpendicular distance between the situations of the two barometers.

So far the operation would be easy and useful, provided its results were attended with sufficient accuracy; but the other above-mentioned causes, which affect the density of the atmosphere, render a variety of corrections necessary for the attainment of a useful degree of accuracy in such measurements. The difficulty of investigating the peculiar effects of those causes, as also of compensating for their effects, involve the operation in a good deal of difficulty, on which account we shall give a full examination of this subject in the note (1.) ; and

shall

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(1.) The mechanical properties of the atmosphere are analogous to the properties of a particular species of curve lines, called *logarithmic curves*; hence the knowledge of the properties of the latter is of considerable assistance in elucidating the properties of the former. But the nature of logarithmic curves is probably not sufficiently understood by the greatest number of my readers: I shall, therefore, briefly subjoin such of their properties as may suffice to illustrate the doctrine of the atmosphere.

#### *Of the Logarithmic Curves.*

*Definitions.* Upon an indefinite right-line AE, fig. 7, Plate XIII. make the intervals AB, BC, CD, &c. equal to one another; or (which is the same thing) make the distances AB, AC, AD, &c. in arithmetical progression. From the points A, B, C, D, E, &c. draw the lines AF, BG, CH, DI,

shall here proceed to give a short idea of the influence of the above-mentioned causes on the densities of the atmosphere, at different altitudes and different times.

In

&c. parallel to each other, and in geometrical progression; viz. making  $A F$  to  $B G$ , as  $B G$  to  $C H$ , as  $C H$  to  $D I$ ; and so on. Then a curve line  $F G H I K$ , drawn through the extremities of those parallel lines, is called a *logarithmic curve*. The indefinite right-line  $A E$  is its *axis*, which will be shewn to be an *asymptote* to the curve, viz. it will never meet the curve; and the lines  $A F$ ,  $B G$ ,  $C H$ ,  $D I$ , &c. are the *ordinates*.

Since the ordinates may be taken in any geometrical proportion, it is evident that there is an infinite variety of logarithmic curves.

**Proposition I.** *The axis  $A E$  is an asymptote to the logarithmic curve.*

Since the ordinates are in geometrical progression,  $H C$  is such a part of  $D I$ , as  $B G$  is of  $H C$ , as  $A F$  is of  $B G$ , as the next ordinate is of  $A F$ , and so on without end; therefore no ordinate can ever be equal to 0; for that 0 would be no part of the preceding ordinate; hence the axis and the curve can never meet; though when produced towards the shorter ordinates, they come continually nearer to each other.

**Prop. II.** *If a tangent and an ordinate be drawn from any point in a logarithmic curve; the subtangent, or part of the axis, which is contained between the intersections of the ordinate and the tangent, is a constant or invariable quantity.*

Take  $E$  and  $F$ , any two points in the curve, fig. 8,

the preceding investigation of the decreasing  
y of the atmosphere, the force of gravity has  
supposed to act uniformly; whereas, in truth,  
force decreases according as the squares of  
the

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XIII. indefinitely near to each other, and through each  
draw a tangent and an ordinate to the curve; TE,  
ing the tangents, and BE, CF, the ordinates. Draw  
ordinate DG, as distant from CF as CF is from  
and through E and F draw En, Fr, both parallel to  
s.

as the distances BC, CD, are equal, we have, from  
initio of the curve,  $DG : FC :: FC : BE$ ; by  
 $\therefore DG - FC : FC :: FC - BE : BE :: Gr : Fr$   
 $: Fr : BE$ .

evident from the parallelism of the lines Fr, En,  
as also of the lines DG, CF, BE, that the trian-  
Gr, FVC, are similar, and so likewise are the trian-  
En, ETB; hence  $Gr : FC :: Fr : VC$ ; also  
 $B : : En : BT :: Gr : FC :: Fr : VC$ . But  
equal to Fr; therefore the subtangent BT must be  
o the subtangent CV.

he same mode of reasoning it may be proved that BT  
l to any other subtangent of the same curve; or that  
tangent is an invariable quantity.

Logarithmic curves, that have equal subtangents,  
ual.

. III. If four ordinates to a logarithmic curve be in  
ne ratio, viz. the first be to the second as the third to  
rth; and if through the extremities of the first and third  
t be drawn, and another secant be drawn through the  
ties of the second and fourth; then the part of the axis  
which

the distances from the centre of the earth increase (p. 61. Part I.); so that the particles of air which are at a distance from the earth gravitate less than those which are nearer to it; hence, on this account, the density

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*which is contained between the intersections of the first secant and the first ordinate, will be equal to that part of the same axis which is contained between the intersections of the second secant and the second ordinate.*

Thus, in fig. 9, Plate XIII. if  $AF : DI :: BG : EK$ , in which case, from the nature of the curve,  $AD = BE$ , and  $AB = DE$ ; and if the secants 'GFT, KIV, be drawn; then TA will be equal to VD.

Through F and I draw FS, and IL, parallel to the axis. Then since  $AF : DI :: BG : EK$ , we have by alternation  $AF : BG :: DI : EK$ ; inversely,  $BG : AF :: EK : DI$ ; and, by division,  $BG - AF (= GS) : AF :: EK - DI (= LK) : DI$ ; inversely,  $AF : GS :: DI : LK$ . But the triangles DIV, LKI, are similar, and so likewise are the triangles AFT, FGS; therefore  $TA : FS :: AF : GS :: (from \ the \ above \ analogy) DI : LK :: VD : IL$ . Then since in the analogy  $TA : FS :: VD : IL$ , the second and fourth terms are equal, viz.  $FS = IL$ , or  $AB = DE$ ; the other two terms must likewise be equal, viz.  $TA = VD$ .

Prop. IV. *The space, which is circumscribed by any two ordinates, and such parts of the curve and of the axis as lie between those ordinates, is equal to the rectangle of the subtangent and the difference of the ordinates.*

Thus, fig. 10, Plate XIII. the space GBEL is equal to  $TE \times SL$ ; TL being the tangent at the point L.

ensity of the atmosphere at a given altitude must be less than if the force of gravity acted uniformly. Yet, since the altitudes of the highest mountains make a trifling addition to the radius of the earth,

the

Imagine  $DI$  to be drawn infinitely near and parallel to  $L$ ; and  $Ir$  to be drawn through the intersection  $I$ , parallel to the axis.

From the similarity of the triangles  $LIr$ ,  $LT E$ , we have  $EL : ET :: Lr : Ir$ ; hence  $ET \times Lr = EL \times$   
= the area  $DEIr$  = (since, when  $ID$  is infinitely near  $EL$ , the triangle  $LIr$  vanishes)  $DEL I$ . And the same thing may be said of any other point very near  $I$ , and another next to that, &c. Therefore (the subtangent  $T$  being an invariable quantity) the sum of all the small areas, such as  $DEL I$ , between  $LE$  and  $BG$ ; or the space  $BELG$ , is equal to  $ET \times LS$  ( $LS$  being the sum of all the differences  $Lr$ ).

*Corollary 1.* The whole area, which is contained between any ordinate  $LE$ , the curve, the axis, and infinitely extended towards  $F A$ , is equal to the rectangle of that ordinate and the subtangent, viz. to  $LE \times TE$ ; since when the area is infinitely extended towards  $A F$ , the last ordinate vanishes, viz.  $EL$  becomes equal to the difference of  $EL$  and the last ordinate.

*Cor. 2.* The spaces, which begin at different ordinates, and are thus infinitely extended, are as the ordinates from which they begin to be reckoned.

*Cor. 3.* The space which lies between any two ordinates, is to the space which lies between any other two ordinates, as the difference of the first two ordinates is to the difference of the two others.

the diminution of the gravitating force will have no sensible influence in our measurements of altitudes by means of the barometer. Those persons, however, who wish not to neglect that circumstance, either

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*Prop. V. The distances, or parts of the axis, which lie between two equal ordinates in two, or more, different logarithmic curves, are as the subtangents of those curves respectively.*

Thus, if in the two logarithmic curves, FIG, QKS, FA be equal to PQ, and BG be equal to HS; then it will be AB : TB :: PH : VH; TG and VS being the tangents.

Draw two ordinates indefinitely near to GB and HS, and draw In, Kr, parallel to the axes; then since AF, LI, BG, are respectively equal to PQ, NK, HS, it will be (from the definition of the curve) AB : LB (or In) :: PH : NH (or Kr); and alternately AB : PH :: In : Kr.

From the similarity of the triangles BGT, GI $\alpha$ , and HSV, SKr, we have BT : In :: BG : nG :: HS : rS :: HV : rK; whence alternately BT : HV :: In : Kr :: AB : PH; and inversely, AB : BT :: PH : HV.

*Scolium.* A table of logarithms is nothing more than a series of numbers in arithmetical progression, annexed to another series of numbers that are in geometrical progression. Therefore, if the lengths of the abscissas AB, AC, AD, &c. of a logarithmic curve, fig. 7, Plate XIII. and the lengths of the corresponding ordinates AF, BG, CH, &c. be expressed in numbers; the former will be the logarithms of the latter.

Since

in such measurements, or in the investigation of properties of the atmosphere, will find the true explanations in the note below.

it increases, and, on the contrary, cold, or a diminution

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: the ratio of the ordinates as well as the lengths of abscissas may be various; it follows that different nomographic curves will represent different systems of logarithms.

The curve which expresses the common table of logarithms, called *Briggs's logarithms*, the lengths of the ordinates,  $1 : 10 : 100 : 1000$ , &c. or their ratio is 10, the abscissas, or the logarithms, are 1, 2, 3, 4, &c.; the subtangent (otherwise called the *module of that system of logarithms*) is equal to 0,43429448.

is evident that every ordinate is a geometrical mean proportional between any two other ordinates equidistant ; whilst its correspondent abscissa is an arithmetical proportional between the abscissas to the other two ordinates. Thus C H, in fig. 7, is a geometrical mean between B G, and D I ; and A C is an arithmetical mean between A B and A D. Hence, for instance, if we divide two equal parts in s, and find a mean geometrical proportional between A F and B G, that mean will be the logarithm of the ordinate s o; and A s is its logarithm.—Thus we find as many ordinates and their logarithms as we

lows from Prop. V. that in different systems of logarithms, the distances between equal ordinates, or the logarithms of equal numbers, are proportional to the subtangents, or modules, of their respective systems. Thus, if

diminution of heat, contracts, the bulk of air. But this expansion and contraction are not regular, viz. they are not exactly proportional to the degrees of heat. Besides this, the rate of expansion, by the same degrees of heat, differs according as the air is more or less dense; also according as it is more or less

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if in one system the module be  $M$ , and the logarithm of a given number be  $L$ ; whilst in another system the module be  $m$ , and the logarithm of the same number be  $l$ ; then it will be  $M : L :: m : l$ ; hence  $Ml = Lm$ ; viz. the product of the logarithm of a given number in one system, multiplied by the module of another system, is equal to the product of the logarithm of the same number in that other system, multiplied by the module of the first system.

If the module of one system be represented by unity; then  $1 : L :: m : l$ ; in which case  $Lm = l$ .

### *Of the ATMOSPHERE.*

Thus much will suffice with respect to the properties of the logarithmic curves; we must now proceed to explain by means of those properties, the constitution of the atmosphere, and the method of determining altitudes from barometrical observations.

It has been already shewn, that the densities of the air at different distances from the earth are in geometrical progression decreasing, whilst the altitudes are in an increasing arithmetical progression; it is therefore evident, that if on a straight line  $AM$ , fig. 12, Plate XIII. the distances  $AB$ ,  $AC$ ,  $AD$ , &c. represent the altitudes, and the straight lines  $AO$ ,  $BF$ ,  $CH$ ,  $DI$ , &c. drawn perpendicular to  $AM$ , represent

is charged with moisture. — The late General Roy, F.R.S. made a great variety of accurate experiments relative to this expansion of air ; but the results of his experiments will be stated in another part of these elements.

### The

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present, or be made proportional to, the densities of the atmosphere at those altitudes ; then a curve line OIN, drawn along the ends O, H, I, &c. of those lines, will be a logarithmic curve, and may be called the *atmospherical logarithmic* ; A M being its axis, and AO, BF, CH, &c. its ordinates. The area which lies between the first ordinate AO, the curve, and the axis, and is infinitely extended towards N, may be considered as being equal to an infinite number of ordinates, situated extremely near to each other ; but those ordinates represent the quantities of air at their respective situations ; therefore the abovementioned area will represent the whole quantity of air in the atmosphere. Also the area, or part of the abovementioned area, from any one of those ordinates upwards, will represent the whole quantity of atmospheric air, which exists beyond that altitude.

This however would be the case if the force of gravity acted uniformly at all distances from the earth, which is not the case. Therefore we must now examine the real diminution of density in the atmosphere on the true hypothesis, viz. of the force of gravity's decreasing according as the squares of the distances increase ; in consequence of which the density of the air at any given altitude must be greater than it would be if the force of gravity acted uniformly, in order that a given degree of pressure may be produced upon the surface of the earth.

The influence of the sun, and principally of the moon, upon the waters of the ocean, is too evident to need any particular examination. And it is evident from the laws of universal attraction, that those celestial

Let PAZ, fig. 13. Plate XIII. represent the circumference of the earth, S its centre,  $m$  SM an indefinite right line passing through the centre S, and intersecting the circumference at A. Let the altitudes SA, SB, SC, SD, differ indefinitely little from each other; but let them be in harmonical progression. Also let the ordinates AO, BF, CG, DH, be proportional to the densities of the atmosphere at A, the surface of the earth, and at the altitudes B, C, D; but upon the supposition that the force of gravity acts uniformly. Then the curve OFGHN, drawn along the extremities of those ordinates, &c. is (from what has been said above) a logarithmic curve.

Now take  $S_b$ , a third proportional to  $S_B$  and  $S_A$ ; take  $S_c$  a third proportional to  $S_C$  and  $S_A$ ; also take  $S_d$  a third proportional to  $S_D$  and  $S_A$ ; viz. let it be

$$S_B : S_A :: S_A : S_b$$

$$S_C : S_A :: S_A : S_c$$

$$S_D : S_A :: S_A : S_d$$

Then  $S_A, S_b, S_c, S_d$ , being the reciprocals of  $S_A, S_B, S_C, S_D$ ; (for they decrease according as  $S_A, S_B, S_C, S_D$ , increase) must be in arithmetical progression; it being well known that the reciprocals of quantities that are harmonically proportional, are in arithmetical progression. See Malcolm's Arithmetic, B. IV. chap. 6.

Through the points A, b, c, d, draw AO, bf, cg, dh perpendicular to the axis Am, and make them proportion-

celestial bodies must act upon the atmosphere in a similar manner ; that is, they must occasion a flux and reflux of the atmosphere, as well as of the ocean : But the atmospherical air being a fluid much

to the *real* densities of the air at A, B, C, D, respectively. Through the points O, f, g, h, &c. draw the curve Ofg b, &c. which will presently be shewn to be a logarithmic curve.

From the abovementioned analogies, we have  $SD \times Sd = \overline{SA^2} = SC \times Sc$ ; hence  $Sc : Sd :: SD : SC$ . Conversely  $Sc : Sc - Sd (= cd) :: SD : SD - SC (= CD)$ ; viz.  $cd : CD :: Sc : SD$ . Or, because CD is indefinitely small, SC will be ultimately equal to SD : whence, by substitution, the last mentioned analogy becomes  $cd : CD :: Sc : SC :: Sc \times SC : SC \times SC :: \overline{SA^2} : \overline{SC^2}$ . Therefore  $cd = DC \times \frac{\overline{SA^2}}{\overline{SC^2}}$ ; and by equal multiplication, it will be  $cd \times cg = CD \times cg \times \frac{\overline{SA^2}}{\overline{SC^2}}$ .

Now CD expresses the bulk of the stratum CDGH (for as CD is very small, the air may, without any sensible error, be supposed to be uniformly dense throughout the stratum CDGH); cg, by construction, expresses the real density of the same stratum, and  $\frac{\overline{SA^2}}{\overline{SC^2}}$  expresses the gravitation of each particle; for since the force of gravity is inversely as the squares of the distances, if the gravity at the surface A be called unity, we have  $\overline{SC^2} : \overline{SA^2} :: 1 : \frac{\overline{SA^2}}{\overline{SC^2}}$  = the gravity at C.

much more variable than water, the action of the sun and moon upon it becomes much less apparent to us, since they must frequently concur with, or be counteracted by, the much more powerful effects of

But the weight, or pressure, of any stratum is as its bulk, as its density, and as its gravity conjointly; therefore  $CD \times cg$

$\times \frac{SA^2}{SC^2}$ , or its equal  $cd \times cg$ , expresses the pressure of

the stratum CDGH. And the same reasoning may be adapted to any other succeeding stratum. But the sum of all such strata as  $cdhg$  (or  $cd \times cg$ ) from  $cg$  downwards, forms the area  $cmsg$  below  $cg$ ; therefore the whole pressure upon C, arising from the gravitation, or pressure, of all the air above it, is as the area  $cmsg$ . But the density  $cg$  of the air is as the pressure; therefore any area as  $cmsg$  below any ordinate, as  $cg$ , is proportional to that ordinate. Now this is a characteristic property of the logarithmic curves; therefore it shews that the curve  $Ofgbn$  is a logarithmic curve. See Cor. 2. to Prop. IV. in page 237.

Farther it appears, that this curve is exactly equal to the curve OFGHN; for if B come continually near to A, and ultimately coincide with it, the ultimate ratio of AB to  $A_b$ , and of BF to  $b_f$ , must be that of equality. Then the tangents OFK, Ofk, form equal angles with the ordinate AO; consequently the subtangents AK, Ak, are equal, and the curves OFGHN, Ofgbn, are also equal. See Cor. to Prop. II. in page 235.

The distances  $Sb$ ,  $Sc$ ,  $Sd$ , are in arithmetical progression, and so are the distances  $A_b$ ,  $A_c$ ,  $A_d$ , because the latter are respectively equal to  $SA - Sb$ ,  $SA - Sc$ ,  $SA - Sd$ .

heat and cold, of dryness and moisture, of winds,  
(See the Abbé Mann's Dissert. on the Flux  
Reflux of the Atmosphere, in the fourth vol. of  
Trans. of the Ac. of Sc. at Brussels, or in the  
Phil.

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Then since  $Og\ln$  is a logarithmic curve, and the  
distances  $Ab$ ,  $Ac$ ,  $Ad$ , are in arithmetical progression; the  
ordinates  $bf$ ,  $cg$ ,  $dh$ , must be in geometrical progression.  
These ordinates represent the real densities of the air at  
 $B$ ,  $C$ ,  $D$ ; therefore the densities of the air at  $B$ ,  $C$ ,  $D$ , are  
in geometrical progression, on the true hypothesis of the de-  
crease of gravity in proportion to the squares of the distances  
from the centre of the earth.

Upon the whole then it appears that the difference be-  
tween the two hypotheses, viz. of an uniform, and of a de-  
creasing gravity, is, that the ordinates  $bf$ ,  $cg$ ,  $dh$ , &c. which  
represent the densities of the air at the places  $B$ ,  $C$ ,  $D$ , re-  
spectively, are a little longer than the corresponding ordi-  
nates  $BF$ ,  $CG$ ,  $DH$ . And they are longer, because the  
distances  $Ab$ ,  $Ac$ ,  $Ad$ , are shorter than the corresponding  
distances  $AB$ ,  $AC$ ,  $AD$ ; recollecting that the curves  
 $G N$ , and  $Og\ln$ , have been demonstrated to be  
similar. So that if the density of the air, or the pressure of  
the atmosphere, at a certain point, for instance,  $D$ , is to be  
calculated on the supposition of an uniform gravity, we must  
determine the value of the ordinate  $DH$ ; but upon the true  
hypothesis of a decreasing gravity, we must determine the value  
of the ordinate  $dh$ .—The method of calculating those ordi-  
nates is as follows.

The logarithmic area  $AONM$  is equal to the rectangle  
 $\times AK$  (Prop. IV. in page 236, and its Corollaries) the

246. *Of the Density and Altitude*

Phil. Magazine, vol. V.) Hence the action of the sun, and principally of the moon, upon the atmosphere, has been long surmised; but it is only of late years that it has been in some measure observed,

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area  $B F N M$  is equal to  $BF \times AK$ ; the area  $C G N M$  is equal to  $CG \times AK$ , &c. Therefore the pressure at the surface, which is proportionate to the area  $A O N M$ , is equal to  $AO \times AK$ . But if the air were of a uniform density, equal to its density at the surface  $A$ , and did not reach higher than  $K$ , its whole quantity would be expressed by  $AO \times AK$ ; therefore the whole quantity of air  $A O N M$ , gradually decreasing in density, is equal to an homogeneous atmosphere of the density  $AO$ , and altitude  $AK$ .

Farther, the quantity of air  $B F N M$  is to the quantity  $A O N M$ , (or to  $AO \times AK$ ) as  $BF$  is to  $AO$ . Also the quantity of air  $C G N M$ , is to the quantity  $A O N M$ , (or to  $AO \times AK$ ) as  $CG$  is to  $AO$ ; and so forth.

Now let fig. 14. Plate XIII. represent the logarithmic curve of the common table of logarithms, where the subtangent, or module  $A E$ , is equal to c,43429; let  $AT$  be equal to  $AO$ , (see both figures) and  $DH$  to  $RY$ ; then we have (by Prop. V. in page 238.)  $AE : AK :: AR : AD$ . Also, if  $VQ$  be equal to  $BF$ , we have  $AE : AK :: VR : BD$ .

Those two analogies are of great practical use, viz. for finding out the pressures or the densities of the atmosphere, when the altitudes are given; and, on the other hand, for finding the altitudes, or the difference between two altitudes, when the densities at those altitudes are known.

The pressures of the atmosphere at different heights, or the values of the ordinates  $AO$ ,  $BF$ ,  $CG$ ,  $DH$ , &c.

observed, and rendered sensible by means of very accurate and long continued barometrical observations; for it may be perceived only by taking a mean of the observations of many years.

Toaldo

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are shewn by the altitudes of the mercury in the barometer, (which are the counterpoises to those pressures) placed at the corresponding situations A, B, C, D, &c. The parts AU, AR, UR, are to be found in the common table of logarithms; AE is equal to 0,43429; and AK has been ascertained, by the following means, to be equal to 26365 feet, or five miles nearly.

When the thermometer stands at  $32^{\circ}$ . and the barometer stands at 30 inches, the specific gravity of air may be reckoned equal to 0,0013065208, and the specific gravity of quicksilver equal to 13,619. Therefore  $0,0013066208 : 13,619 :: 1 : 10423,07 =$  the specific gravity of quicksilver, when that of air is called one, viz. in the above-mentioned circumstances quicksilver weighs 10423,07 times as much as air: whence it follows that a perpendicular pillar of quicksilver of 30 inches in the barometer, is a counterpoise to a perpendicular pillar of the atmosphere of the same diameter, reaching from the surface of the earth to the utmost limit M of the atmosphere, or to a perpendicular pillar of air of an uniform density (viz. of the density at the surface A, such as is indicated by the ordinate AU), but of 30 times 10423,07 inches, viz. of 312692,1 inches. Therefore AK, which is the subtangent, or the module of the atmospherical logarithmic, is equal to 312692,1 inches, or 26057,675 feet, or 8685,891 yards, or 4342,945 fathoms, or 5 miles, minus 342,325 feet.

Toaldo the learned astronomer of Padua, after a variety of observations made in the course of several years, found reason to assert, that *ceteris paribus*, at the time of the moon's apogeeum, the mercury in the

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The practical application of the abovementioned analogies, to the method of measuring altitudes by means of barometrical observations, will be illustrated by one or two examples.

*Example I.* Suppose that the mercury in the barometer at A, fig. 13. viz. on the surface of the earth, stands at 30 inches, at the same time that the mercury of a similar barometer situated on the top of a mountain at D, stands at 29,34 inches. It is required to deduce the altitude A D from those observations.

In the first place it must be recollect'd, that the same pressure of the atmosphere, which causes a certain density of the air at any place A, or D, keeps up the mercury in the tube of the baromer; therefore the altitudes of the mercury in the barometers situated at different altitudes above the surface of the earth, are proportional to the densities of the air, or to the ordinates of the atmospherical logarithmic at those respective altitudes. So that in the present instance, 30 inches perpendicular altitude of mercury represents the ordinate A O, and 29,34 inches perpendicular altitude of mercury represents the ordinate D H.

Now in the logarithmic curve of the common tabular logarithms, fig. 14, Plate XIII. A T and R Y are respectively equal to A O and D H of the atmospherical logarithmic, fig. 13, Plate XIII.; therefore, taking from the common logarithmic tables, the logarithm of 30, which

the barometer rises the 0,015 of an inch higher than at the perigeum; that at the time of the quadratures, the mercury stands 0,008 of an inch higher than at the time of the syzyges; and that it stands

0,022

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is 1,4771213; also the logarithm of 29,34, which is 1,4674601; and subtracting the latter from the former, we obtain the remainder 0,0096612, which is equal to the portion A R of the axis.

This being obtained, we then say A E : A K :: A R : A D; viz. 0,4342945 : 26057,675 :: 0,0096612 : to a fourth proportional, which gives the altitude A D equal to 579,672 feet.

In finding this fourth proportional, according to the common rule of three, we may either multiply the third term by the second, and then divide the product by the first; or we may first of all divide the second term by the first, and then multiply the quotient by the third term; the result, as is well known, turning out always the same. But in this operation the second method is attended with a practical advantage, which will be pointed out presently.

*Example II.* Suppose the perpendicular pillar of mercury in the barometer at B, to be 28,65 inches, and that of the mercury in a similar barometer at D, to be 26,97 inches. It is required to determine thereby the perpendicular distance BD, between the two stations, or places of observation.

Supposing the ordinates U Q, R Y, to be respectively equal to the above-mentioned mercurial altitudes; we take the logarithm of 28,65, which is 1,4571246, and the logarithm of 26,97, which is 1,4308809; then subtracting the latter

0,022 of an inch higher when the moon in each lunation comes nearest to our zenith (meaning the zenith of Padua, where the observations were made) than when it goes farthest from it. *Journal des Sciences Utiles.*

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latter from the former, the remainder 0,0262437 is equal to U R.

This being obtained, we then say, as mentioned above, page 246,  $A E : A K :: V R : B D$ ; viz.  $0,4342945 : 26057,675 :: 0,0262437$ : to a fourth proportional, to find which, we divide the second term by the first, and obtain the quotient 60000; then multiply the third term by this quotient, and the product, viz. 1574,622 feet, is the distance BD.

Here it is to be observed, that the first and second terms of the abovementioned analogy, are constantly the same, viz.  $0,4342945$ , and  $26057,675$ ; and of course their quotient is likewise constantly the same, namely, the very convenient number 60000; therefore the operation of determining the altitudes, &c. may be rendered very short; for the whole consists in multiplying the difference of the logarithms of the mercurial altitudes, by 60000, and the product gives the altitude sought, in feet. And if we want the answer in fathoms, the operation will be rendered shorter still; for since six feet are equal to one fathom, 60000 feet must be equal to 10000 fathoms. Therefore, in that case, we need only multiply the difference of the logarithms by 10000; which is easily done by removing the comma, which separates the decimal part of the logarithmic remainder, four places of figures to the right. Thus, in the last example, the logarithmic

In the 7th vol. of the Philosophical Magazine, there is a paper of L. Howard, Esq. which contains several curious observations relative to this subject. This gentleman found both from his own observations,

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arithmic remainder is 0,0262437, which, by removing the comma four places to the right, becomes 262,437, and expresses the distance BD in fathoms; the same as before, 262,437 fathoms being equal 1574,622 feet.

It is now necessary to recollect that this rule has been established upon the suppositions that the specific gravity of mercury is 13,619; that the specific gravity of air is 0,0013066208; that the temperature of the air, as well as of the mercury, is 32°. and that the mercurial altitude in the barometer, situated on the surface of the earth, is equal to 30 inches. But if any one of those circumstances happens to be altered, then the result of the operation, according to the above-mentioned rule, will deviate more or less from the truth. For instance, if the temperature happens to be higher than 32°. then the specific gravities of the air, and of the mercury, will differ from the above-mentioned statements, and of course the module of the atmospherical logarithmic, which is the second term of the analogy, &c. must be altered accordingly.—The same thing may be said with respect to the other particulars.

Notwithstanding the intricacy of solution which arises from the concurrence and fluctuation of the above-mentioned circumstances, the particular effects of each cause have been examined, with immense trouble and assiduity, by various ingenious philosophers; and rules have been formed for correcting in a great measure the errors

observations, and from an examination of the Meteorological Journal of the Royal Society, which is published annually in the Phil. Transactions, that the moon had a manifest action upon the barometer.

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which arise therefrom. We shall now proceed to examine those rules, and the facts upon which they are established.

Since the bulks of bodies are increased by the accession of heat, and of course their specific gravities are thereby diminished; and since different bodies are expanded differently by equal increments of heat; it follows that, under the same atmospherical pressure, the mercury in the barometer must stand higher or lower, according as it is hotter or colder. Also the ratio of the gravity of mercury to that of air, will, *cæteris paribus*, vary with the increase or decrease of temperature; but this variation has been found to be not exactly proportional to the degrees of heat. Hence in measuring altitudes by the barometer, either the subtangent of the atmospherical logarithmic must be derived from the actual temperature of the mercury and of the air at the time of making the observations; or both the actual density of the air, and the observed altitude of the mercury in the barometer, must be reduced to what they would be if the degree of temperature were  $32^{\circ}$ .—The latter method is the most expeditious.

Mercury has been found to expand nearly in the exact proportion of the degrees of heat; its expansion for every degree of heat, from  $32^{\circ}$ . upwards, or the contraction for every degree of heat from  $32^{\circ}$ . downwards is equal to  $0,000102$  of the whole bulk, which at  $32^{\circ}$ . is called one

meter. " It appears, he says, to me evident, that  
" the atmosphere is subject to a periodical change  
" of gravity, whereby the barometer, on a mean of  
" ten years, is depressed at least one-tenth of an  
" inch

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or unity: so that if a quantity of quicksilver, which at the temperature of  $32^{\circ}$ . measures one cubic inch, at the temperature of  $33^{\circ}$ . measure 1,000102 inches; it will, at the temperature of  $34^{\circ}$ . measure 1,000204 inches, &c. But though quicksilver in itself be expanded regularly by the accession of heat; yet in the tube of the barometer, the perpendicular pillar of it is not expanded with the same regularity; and this deviation from that regularity is owing to two causes, viz. to the expansion of the glass tube, and to the probable generation of some elastic fluid, which being extricated from the mercury by the heat, occupies the empty part of the barometrical tube above the quicksilver.

The actual increase of altitude in a barometrical pillar of mercury, arising from an increase of temperature, was determined from actual experiments on the barometer itself, by the late very ingenious General Roy. When the barometer stood at 30 inches, this gentleman exposed a barometer to different degrees of heat in a very proper apparatus, wherein the whole column could be rendered of the same uniform temperature; and measured the increase or decrease of altitude, which was occasioned by the various degrees of heat. (See his valuable paper in the 67th vol. of the Philosophical Transactions.) The result of his experiments is contained in the annexed table, where the first column expresses the degrees of heat, to which the barometer was exposed; the second column shews the altitudes of the mer-

by F. Balfour, Esq. During the month of April, beginning from six o'clock in the morning, the barometer rose a little during four hours, then fell during eight hours; after which it rose again during

part of it, in which case the supposed vapour, which is extricated from the mercury by the heat, is less in quantity, and finds a greater space to expand itself in; therefore the irregularity of apparent expansion, which is occasioned by this vapour, is not so great as when the column of quicksilver in the barometer is 30 inches; so that if the experiments were performed with a column of 15 inches, the expansions would not come out exactly the halves of those which are stated in the table, which are the results of experiments performed with a column of twice 15, viz. 30 inches; the difference however, would not be very considerable.

In order to apply the correction for the expansion, we must find, by means of the preceding table, what the column of mercury would be, if the quicksilver of the barometer had been at the temperature of  $32^{\circ}$ . instead of its actual temperature. For this purpose the actual temperature of the mercury, which is ascertained by means of the thermometer, must be found out in the first column of the table, and opposite to it is the expansion for a column of 30 inches, or its bulk at that temperature. Then say, as this bulk is to 30 inches, so is the observed altitude of the mercury in the barometer, to a fourth proportional, which is the corrected altitude. Thus, if the observed altitude be 28 inches, and the temperature of the mercury be  $72^{\circ}$ . you will find 30,1302 against  $72^{\circ}$ . in the table; therefore say, as  $30,1302 : 30 :: 28 : \text{to a fourth proportional, which is}$

ing four hours, and then fell during the last 8 hours of the 24. And this took place every day regularly, with very few exceptions.

But it seems, that those regular fluctuations of the barometer at Calcutta could not be owing to the immediate action of the moon, since the moon could not cross the meridian every day at the same time. So that upon the whole it appears that we have very little, if any, proof of the existence of a diurnal flux and reflux of the atmosphere, similar to the tides of the sea; yet the causes which render the diurnal tide of the atmosphere insensible to us, may be the elasticity of the air, and the interference of the much more powerful effects of heat, cold, vapours, &c.

Having thus given a sufficient idea of the nature and extent of the atmosphere, and of the use of the barometer, I shall conclude this chapter with a list of the altitudes of several remarkable mountains, hills, and other places, which have been ascertained by various ingenious persons, either geometrically or by means

of

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27,879 inches; so that had the temperature of the mercury in the barometer been  $32^{\circ}$ . the observed barometrical altitude would have been not 28, but 27.879 inches.—If the degree of temperature be not mentioned in the table, then we must take a proportional part of the difference of the contiguous expansions in the third column of the table, and must add it to the expansion next below; for the sum will

of barometrical observations. I have, however, preferred the result of the geometrical measurement to that of the barometrical, for all those places which have been measured by both means.

**TABLE of HEIGHTS, expressed in English Feet, as determined by M. De Luc, Sir George Shuckburgh, Col. Roy, Mr. Bouguer, and other scientific Persons.**

[N. B. The letter G, which follows some of the names, means that such altitude was measured geometrically.]

<i>In AMERICA.</i>					<i>Above the Ocean.</i>
Chimboraçon	—	—	—	—	19595
Cayambourow	—	—	—	—	19391
Antisana	—	—	—	—	19295
Pichinha	—	—	—	—	15670
City of Quito	—	—	—	—	9377

*In AFRICA.*

Table Mountain at the Cape of Good Hope	—	—	—	—	3454
Gondar City, in Abyssinia	—	—	—	—	8440
Pic of Teneriffe (by De Borda, 11022 feet high)	—	—	—	—	14026
Pic Ruivo in Madeira	—	—	—	—	5141

*h*

be the actual bulk of a column, which at  $32^{\circ}$ . would be 30 inches high.

Thus if the observed altitude be 28 inches, and the temperature  $47^{\circ}$ . then  $47^{\circ}$ . is not to be found in the table; but  $47^{\circ}$ . is equally distant from  $42^{\circ}$ . and  $52^{\circ}$ . which are in the table.

## In EUROPE.

Above the Me-  
diterranean.

The summit of Mont Blanc, the highest of the Alps, and, as Sir George Shuckburgh supposes, the most elevated point in Europe, Asia, and Africa. G. — — —	15662
It stands 14432 feet above the Lake of Geneva. G.	
Monte Rosa, being the second mountain of the Alps. G. — . —	15084
Chamouny, ground-floor of the inn near the foot of Mont Blanc — —	3367
The lake of Geneva . . — . —	1230
The deepest part of the lake of Geneva · The greatest depth of the lake being 393 feet.	837
Aiguille d'Argentière. G. — —	13402
The summit of the Glaciere de Buet. G.	10124
The Dole, highest point of Mont Jura. G. — — —	5523
Piton, highest point of Mont Saleve. G.	4514
	Summit

table; therefore we take the half of the difference of the expansions for those degrees, viz. the half of 0,0328, which is 0,0164, and add it to 30,0333; the sum 30,0497 is the bulk answering to 47°. Then we proceed as before, viz. say as 30,0497 : 30 :: 28 : to a fourth proportional, &c.

Notwithstanding the great accuracy of Col. Roy's experiments, it is believed that his statements of the expansions

Above the Me-  
diterranean.

Summit of the Mole	—	—	6113
St. Joire, in a field at the foot of the Mole. G.	—	—	1901
The source of the river Arviron, at the bottom of the Vallée de Glace	—	—	3656
The ball on the highest, or south-west, tower of St. Peter's church in Ge- neva (249 feet above the lake) G.	—	—	1479
Frangy, at the inn, first-floor, below the lake of Geneva	—	166	
Aix, à la ville de Genève, first- floor, below the lake of Geneva	—	378	
Chambery, au St. Jean Baptiste, first-floor, below the lake of G.	—	350	
Aiguebelles, at the inn, first-floor, below the lake of Geneva	—	190	
La Chambre, at the inn, first-floor, above the lake of Geneva	—	337	
St. Michael, at the inn, first-floor, above the lake of Geneva	—	1113	2343
Modane, at the inn, first-floor, above the lake of Geneva	—	2220	3450
			Monte

are rather too great, and that the mean expansion of an inch of mercury for each degree of Fahrenheit's thermometer, between 20°. and 70°. (within which extremes most barometrical observations are made) is 0,000102 of an inch. But it is highly probable that different specimens of mercury follow different rates of expansion. Admitting then the last mentioned expansion, we derive therefrom an easier method:

Above the Me-  
diterranean.

G. — — —	9997
, the foot of Mont Cenis, first-floor — —	4408
, at the post — —	6261
t of Mont Cenis — —	9212
at the foot of Mont Cenis, side of Italy, at the inn, — — —	2741
Keyes, one of the Pyrénées li, one of the Pyrénées -	7620
o, one of the Pyrénées -	9300
ne of the Pyrénées — -	11700
Iotel d'Angleterre, second-	8544
— — — —	941
t. Marco, first-floor — -	263
Paon, first-floor — —	307
Pelerin, first-floor — -	399
ittle village on the Appen- neen Bologna and Florence	2591
in Raticosa — —	2901

The

the altitude, viz. a method which does not re-

For this purpose we multiply the inches of barometrical altitude by 0,000102, and multiply by the difference of degrees between 32°. and the temperature of the mercury; then we add the last observed barometrical altitude, when the temperature of the mercury is above 32°. or subtract it from it when the temperature is below 32°. and the remainder is the corrected altitude.

The summit of Monte Velino, one of the Appenines, covered with snow in June; about 46 geographical miles, N.W. of Rome, and which is probably the highest of the Appenines. G. — — —

Above the Mediterranean.

8397

Florence, nel Corso dei Tintori, 50 feet above the Arno, which was 18 feet below the wall of the quay — —

240

Pisa, aux Trois Demoiselles, second-floor

54½

Siena, aux Trois Rois, second-floor

1066

Redicoffani, at the Post, first floor

2470

Redicoffani, the top of the tower of the old fortification on the summit of the rock — — —

3060

Viterbo, aux Trois Rois, first-floor, on the Ciminus of the Ancients — —

1259

Rome, nel Corso, 61 feet above the Tyber — — — —

94

The river Tyber at Rome — —

33

Places

Thus, using the suppositions of the preceding example, the temperature  $72^{\circ}$ . exceeds  $32^{\circ}$ . by  $40^{\circ}$ ; therefore we multiply 28 (which is the observed barometrical altitude) by 0,000102, and multiply the product 0,002856 by 40, which produces 0,11424; then subtract this last product from 28, and the remainder 27,88576 inches, is the corrected barometrical altitude; which differs from the result of the other method by about one 500th part of an inch.

The next consideration relates to the expansion of air by heat; and the investigation and application of this expansion

are

Places in ROME.	Above the Tyber.	Above the Me- diterranean.
The top of the Janiculum, near the Villa Spada — — 260		293
Aventine Hill, near the Priory of Malta — — — 117		150
In the Forum, near the Arch of Severus, where the ground is raised 23 $\frac{1}{2}$ feet — — 34		67
Palatine Hill, on the floor of the Imperial Palace — — 133		166
Celian Hill, near the Claudian aqueduct — — — 125		158
Bottom of the canal of the Clau- dian aqueduct — — 175		208
Esquiline Hill, on the floor of St. M. Major's church — — 154		187
Capitol Hill, on the west-end of the Tarpeian rock — 118		151
The union of the Viminal and Quirinal Hills, in the Carthu- rian's church; Diocles. Baths 141	174	
Pincian Hill, in the garden of the Villa Medici — — 165	198	
		Top

are by far the most intricate and perplexing particulars of the subject; for the air does not only expand irregularly through a progressive increase of heat; but its expansibility is different according both to its density and to its purity.

The best contrived, the most extensive, and the most conclusive experiments relative to this expansibility, were

*Of the Density and Altitude*

	Above the Tyber.	Above the Mediterranean.
Top of the cross of St. Peter's ch.	502	535
The base of the obelisk, in the centre of the Peristyle	— 31	64
The summit of the mountain Soracte, lying about $20\frac{1}{2}$ geographical miles north of Rome, G.	—	2271
Mount Vesuvius, in the kingdom of Naples. Mouth of the crater from whence the fire issued in 1776	—	3938
Mount Vesuvius, at the base of the cone	— — — —	2021
Top of the mountain Somma, adjoining to Vesuvius	— — —	3738
The summit of mount Ætna, in Sicily		10954
Barberino di Valdensa, between Boggeborni and Tavernelle	— —	974
Modena, <i>a l'Albergo nuovo</i>	— —	214
Montmelian, at 20 feet above the river		811
Pont Beauvoisin	— — —	705
		La

made by the same abovementioned gentleman, Col. Roy, afterwards General Roy. The manner of performing those experiments, and their results, will be mentioned in a more proper part of this work.

For the present purpose we shall only observe, that if the stratum of air, which lies between the two stations of the barometer, were of an uniform temperature, and of an uniform degree of moisture; or even if it were of a certain progressively increasing or decreasing temperature; rules might be

Above the sea,

La tour du Pin	—	—	—	938
Verpilliere	—	—	—	566
Lyons, at the Hotel Blanc, 50 feet above the Soane	—	—	—	449
St. Jean la Vieux	—	—	—	695
Cerdon, near the post-house at the foot of the rocks	—	—	—	854
Nantua, 10 feet above the lake	—	—	—	1423
Chatillon, at the <i>Logis Neuf</i>	—	—	—	1629
Colonges	—	—	—	1626
St. Genis, apparently on a level with the foot of Mont Jura	—	—	—	1501
Macon, at the Parc, 24 feet above the Soane	—	—	—	514
Dijon, à la Cloche, the first-floor	—	—	—	710
Auxerre, 50 feet above the river	—	—	—	283
Sens, at the post	—	—	—	163
Fontainbleau, at the <i>Grand Cerf</i> , se- cond-floor	—	—	—	242
Paris, mean height of the Seine, viz. <i>quand les eaux se trouvent à 13 pieds</i> <i>9 pouces sur l'échelle du Pont Royal</i> , <i>selon M. de Lalande</i>	—	—	—	36 $\frac{1}{2}$
				Mr.

derived for correcting the effects of aerial expansion. However, the practicability of ascertaining the various but contemporaneous temperature and moisture of a considerable stratum of air, seems, at least for the present, to be utterly out of our power.

In

M. de Lalande's observatory, at the College Royal, first-floor, above the Seine, at Paris — 101.	Above the Sea
	137 $\frac{1}{2}$
Stone gallery of the church on Mount Valerien, above the Seine, Paris — — — 473	509 $\frac{1}{2}$
Depth of the cave of the Royal Observatory at Paris, below the pavement — — — 98	
Height of the North Tower of the church of <i>Notre Dame</i> at Paris, above the floor. G. — 218 $\frac{1}{2}$	
Chantilly — — —	119
Clermont — — —	329
Amiens, <i>Rue de Noyon</i> , first-floor	147
Abbeville, first-floor — —	79
Mean height of the river Thames at London (viz. when the water is $15\frac{1}{2}$ feet below the pave- ment in the left-hand arcade at Buckingham-stairs) which is above the mean height of the river Seine at Paris 6,8 : —	43

Iron

In the present state of knowledge, the only correction we can apply is founded upon the supposition that the temperature of the whole stratum of air, which lies between two stations, is the mean of the temperatures of the air at the two stations; and that air of the more common degree of moisture is expanded, at a mean 0,00245 of its bulk, which is

Iron gallery over the Dome of St. Paul's church, in London above the church-yard, North side. G. — — —	Above the Sea. 281
The top of the cross on the dome of the same, above the ground without — — —	340
Height of the Pagoda in Kew- gardens. G. — — —	116½
Warwick, mean level of the ri- ver Avon — — — —	155
Peak of Snowdon in North Wales —	3555
Moel Eilio, North Wales — —	2371
Whernside — — — —	4050
Pendle-hill. — — — —	3411
Pennygant — — — —	3930
Ingleborough — — — —	3987
Halvellyn — — — —	3324
Skiddaw — — — —	3270
Cross-fell — — — —	3390
Saddleback — — — —	3048
	Ben-

is called *one*, by each degree of Fahrenheit's thermometer, between 20°. and 70°. which is the range of temperature through which most barometrical observations are likely to be made.—The rule then, which is established upon those suppositions, is as follows:

Multiply the difference between 32°. and the mean tem-  
perature of the air, (viz. the mean between the temperatures  
of the air, observed at the two stations) by 0,00245, and  
multiply

	Above the Sea.
Ben-Moir — — — —	3723
Ben-Laurs — — — —	3858
Ben-Gloe — — — —	3472
Ben-Lomond — — — —	3180
Benevish — — — —	4350
Shihallion — — — —	3461
Tinto — — — —	2342
Calton Hill, above Leith Pier-head, Scotland. G. — —	344
Arthur's seat, above Leith Pier-head, Scotland. G. — —	803
Base of Hawk-hill Observatory, above the bottom of the small rock on Arthur's seat, Scotland. G. — — —	684
Mount Hekla in Iceland — —	4887

The

multiply the product by the approximated perpendicular distance, already found, between the two stations, and the last product must be added to, or subtracted from (according as the mean temperature of the air is above or below 32°.) the approximated altitude ; and the sum or difference is the correct altitude.

For if what we have called the approximated elevation gives the real distance between the two stations when the mean temperature of the air is 32°. it is evident that when the air is one degree hotter, its bulk is 0,00245 larger ; hence in this case the same weight, or the same pressure on the mercury of the barometer, is produced by a stratum of air

The Caspian sea is said (by Mr. Lacre) to be 306 feet below the ocean.

The

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air thicker than the former by 0,00245 of the whole, viz. of the whole number of feet, or fathoms, by which that thickness is expressed; hence the quantity 0,00245 must be multiplied by the number of feet or fathoms, which would express the real thickness of the stratum if its temperature were 32°.—It is also evident, that if one degree of heat increases the stratum 0,00245 of the whole, two degrees must increase it of twice that quantity; three degrees, of three times that quantity, &c. Therefore the above-mentioned product must be also multiplied by the number of the degrees of heat, &c.

Having thus shewn the foundation of the method of applying the barometer to the measurement of altitudes, in separate parts, for the sake of perspicuity, I shall now collect all the necessary rules under one point of view; which may be considered as the ultimate result of the investigation.

I. For this purpose two accurate barometers, as nearly as possible of the same construction, must be had; and each barometer must be furnished with a thermometer, which must be attached to it in such a manner as to have its bulb in contact, or nearly in contact, with the mercury of the cistern of the barometer. Two other separate thermometers must likewise be provided.

One barometer and a detached thermometer must be situated at each of the two places, between which the perpendicular distance is required to be measured; and the observations at both places must be made by two observers, at the very same time; observing the altitude of the mercury in the barometer, the temperature of its mercury, which is indicated by the attached thermometer, and the temperature of

would make upon a globe of two feet in diameter. This calculation is made by saying, as the diameter of the earth is to the altitude of the highest mountain, so is a diameter of two feet to a fourth proportional, which being found by the rule of three, is the height of a similar mountain on a globe of two feet in diameter.

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mentioned constant quantity 0,00245, viz. it must be multiplied by the difference of degrees between  $32^{\circ}$ . and the mean temperature of the air, as also by the approximated elevation, &c. as mentioned in the preceding paragraph.

N. B. There are some other ways of performing this problem, and of applying the corrections; but I have preferred the above as being the most accurate; and more evidently deduced from the foregoing principles.

an. Expansion of common air for each degree of Fahrenheit's Thermometer between 12°. and 92°. and under different pressures, as indicated by the height of the mercury in the barometer, from 19 to 30  $\frac{1}{2}$  inches.

12°.	22°.	32°.	42°	52°.	62°.	72°.	82°.	92°.
1. 0,00133	0,00139	0,00144	0,00149	0,00155	0,00152	0,00149	0,00144	
2. 0,0016	0,00167	0,00173	0,0018	0,00187	0,00183	0,0018	0,00173	
3. 0,0016	0,00167	0,00173	0,0018	0,00187	0,00183	0,0018	0,00173	
4. 0,0016	0,00167	0,00173	0,0018	0,00187	0,00183	0,0018	0,00173	
5. 0,00188	0,00195	0,00203	0,0021	0,00218	0,00214	0,0021	0,00203	
6. 0,00188	0,00195	0,00203	0,0021	0,00218	0,00214	0,0021	0,00203	
6,5 0,00201	0,00209	0,00218	0,00226	0,00234	0,0023	0,00226	0,00218	
7. 0,00206	0,00214	0,00222	0,00231	0,00239	0,00235	0,00231	0,00222	
17,5 0,0021	0,00219	0,00227	0,00236	0,00245	0,0024	0,00236	0,00227	
28. 0,00215	0,00224	0,00232	0,00241	0,0025	0,00245	0,00241	0,00232	
18,5 0,00219	0,00228	0,00237	0,00246	0,00255	0,00251	0,00246	0,00233	
19. 0,00224	0,0023	0,00242	0,00251	0,0026	0,00256	0,00251	0,0024	
20. 0,00228	0,00233	0,00247	0,00256	0,00266	0,00261	0,00256	0,0024	
21. 0,00233	0,00242	0,00252	0,0026	0,00271	0,00265	0,00261	0,0025	
22. 0,00237	0,00247	0,00257	0,00266	0,00276	0,00271	0,00265	0,0025	

*Example I.* It is required to determine the perpendicular distance between the summit and the foot of a hill, from the following observations:

Altitude of the barometer.	Temperature of mercury.	Temper. of air.
At the foot of the hill — 29,561 inches — 63° — 56°		
At the summit of the hill 28,272 inches — 54° — 48°		

From the table in page 254, we find the bulk of mercury for 63°. equal to 30.1; therefore 30.1 : 30 :: 29,561 : to the reduced barometrical altitude, 29,462.

The bulk of mercury for 54°. is, from the table, 30,0726; therefore 30,0726 : 30 :: 28,272 : to the reduced barometrical altitude, 28,204.

The logarithm of 29,462 is 1,4692622

The logarithm of 28,204 is 1,4503107

The difference of those log. is 0,0189515

Now if the comma be removed four places towards the right hand, this remainder will express the approximated elevation in fathoms; viz. 189,515 fathoms. Or if it be multiplied by 60000, it will express the same approximated elevation in feet, viz. (0,0189515 × 60000 =) 1137,09 feet.

The mean temperature of the air is  $\left(\frac{56^\circ + 48^\circ}{2} =\right) 52^\circ$ .

which exceeds 32° by 20°; therefore (0,00245 × 20 × 1137,09 =) 55,71741, which, since the mean temperature of the air is above 32°, must be added to the approximated elevation, and their sum, viz. (1137,09 + 55,71741 =) 1192,80741 feet, is the correct elevation, or the perpendicular altitude of the hill.

For the sake of greater accuracy, the expansion of the air may be taken from the preceding table, according to the last part of the rule; viz. the mean between the reduced barometrical altitudes is  $\left(\frac{29,462 + 28,204}{2} =\right) 28,833$ ; and

an temperature of the air is  $52^{\circ}$ . Then in the table I facing 28,5, which is the nearest to 28,833; and  $52^{\circ}$ , or properly under the degrees of heat between 1d  $62^{\circ}$ . the quantity 0,00255, which quantity must be instead of 0,00245; therefore  $(0,00255 \times 20^{\circ} \times 9 = ) 57,99159$ , which being added to the approximate elevation, gives  $(1137,09 + 57,99, \text{ &c. } = ) 1195,08$  the altitude of the hill, which is a nearer approximation to the truth.

*Exple II.* It is required to determine the perpendicular distance between two situations, where the following observations were made.

	Bar. altit.	Att. Therin.	Det. Ther.
place	- - 29,883	- - $28^{\circ}$ .	- - $24^{\circ}$ .
place	- - 29,032	- - $26^{\circ}$ .	- - $26^{\circ}$ .

In the table in page 254, we have the bulk of mercury at  $28^{\circ}$ . equal to 29,9865; therefore say, 29,9865 : 29,883 : to the reduced barometrical altitude

the bulk of mercury for  $26^{\circ}$ . is 29,98; therefore 29,98 : 30 :: 29,032 : to the reduced barometrical altitude 29,051,

logarithm of 29,897 is 1,4756276

logarithm of 29,051 is 1,4631611

difference of those log's. is 0,0124665, which, by removing the comma four places to the right, expresses the estimated elevation in fathoms, viz. 124,665 fathoms. multiplied by 60000, will express it in feet, viz.  $(124,665 \times 60000) 747,99$  feet.

mean temperature of the air is  $(\frac{24^{\circ} + 26^{\circ}}{2} = ) 25^{\circ}$ ,

It is also necessary to observe, that in different latitudes neither the gravity nor the expansibility of air is the same. Hence the ratio of the gravity of air to that of mercury is by no means constant; nor is it easily ascertained for any particular place and time. In the province of Quito in Peru, which stands considerably above the level of the ocean, the altitudes which are deduced from barometrical observations, fall greatly short of the real or geometrical mensurations; whereas at Spitzbergen, they greatly exceed the truth. "It seems," as Col. Roy justly observes, "that the atmosphere surrounding our globe might possibly be composed of particles, whose specific gravities were really different; that the lightest were placed at the equator, and that the density of the others gradually increased from thence towards the poles, where the heaviest of all had their position."

This supposition is corroborated by two obvious considerations, namely, that on account of the cold the air about the poles of the earth is much dryer than in other places, and that on account of the polar diameter being shorter than the equatorial diameter, the air which lies at equal distances from the surface of the earth, is actually nearer to the centre of attraction about the poles than about the equator. We may therefore conclude, upon the whole, that in order to render the barometrical measurement capable of greater accuracy than it is at present, farther experiments and observations must be made with all possible attention, in different latitudes, and in different states of the atmosphere. It is also probable that it will be found useful to accompany with the barometer and thermometer, the use of other instruments, such as the hygrometer, the electrometer, and the manometer.

Those persons who wish to examine this subject in a more particular

articular manner, may consult the following valuable publications: M. de Luc's *Recherches sur les Modifications de l'Atmosphère*. Dr. Horsley's Paper in the Philosophical Transactions, vol. 64th, Sir George Shuckburgh's Paper, A. de Luc's Paper, and Col. Roy's Paper, all three in the 7th vol. of the Philosophical Transactions. Also the article *Pneumatics* in the Encyclopædia Britannica.

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## CHAPTER X.

## OF AIR IN MOTION, OR OF THE WIND.

THE weight and pressure of the atmospherical air have been explained in the preceding chapters. It is now necessary to examine the particulars which relate to the motion of the same fluid, and those particulars may be arranged under two principal denominations, viz. of *wind*, and of *sound*.

Wind, or a current of air, is the progressive motion of air from one place to another. Sound, or the sensation which we perceive through our ears is produced by a vibratory motion of the sounding body, and is conveyed to the ear by a vibratory motion of the particles of air, or other body which intervenes between the sounding body and the ear.

above-mentioned velocity ; because that variation is attended with a proportionate density of the atmosphere.

II. The velocity with which air of the usual density will rush into a vessel containing air less dense, may also be easily calculated ; for in this case, we must consider the air as pressed not by the whole atmosphere, but by the difference between the whole atmosphere, and that part of it which produces the density of the air in the vessel. Or, in other words, the altitude of an homogeneous atmosphere must be reduced in the proportion of the usual density of the air at the surface of the earth, to the density of the air in the vessel ; the rest of the calculation proceeds exactly as in the preceding case. The velocity, however, which is obtained by this means, will be gradually checked and diminished, because by the entrance of the external air, the quantity, and, of course, the density of the air in the vessel, is gradually increased.

The like calculations may be easily and evidently applied to the entrance of air, which is pressed by any given pressure greater or less than that of the whole atmosphere ; as also to the efflux through a given aperture, of air, which has been confined in a given vessel by a given weight. But in practice, both the influx and the efflux of air into, or out of, a given vessel through a given aperture, turn out by much different from the determinations of the theoretical calculations ; which is owing to the same

ame concurring and fluctuating causes, as have in chap. VII. of this Part, been shown to affect the movements of non-elastic fluids, viz. the attraction of aggregation, the attraction of cohesion, the formation of the *vena contracta* in certain case, the want, or the assistance, of an ajutage or short pipe to the aperture, the different directions which different parts or filaments of fluid acquire in their motion, the friction, &c. And in elastic fluids such variations must evidently be greater than in water, and other non-elastic fluids.

The same observations may be made with respect to the passage of air, and other elastic fluids, through long pipes, channels, &c. which retard its velocity in a very great degree, and the irregularity is so great, that no known theory is sufficient to determine the effect in most cases.

The quantity of air discharged into the atmosphere, through a given aperture in a vessel, wherein the air is pressed by a given weight, as appears from Dr. Young's Experiments, seems to be nearly as the square-root of the pressure; and that the ratio of the expenditures by different apertures, with the same pressure, lay between the ratio of their diameters, and that of their areas\*.

III. The velocity and the force of the wind, or a natural current of air, deserve to be examined

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\* Philosophical Transactions for 1800. P. I.

with

with all possible attention ; it being owing to that current that we are enabled to navigate the ocean, to make use of windmills, &c. But the obstruction which the motion of air receives from the various causes that have been mentioned in speaking of non-elastic as well as of elastic fluids, in the IVth and in the present Chapter of this Second Part of these Elements, invalidates the application of every theory, and renders the results of actual experiments the only guides which can direct us in the use and application of the winds.

The velocity of air in natural currents of certain denominations, has been attempted to be measured by various means. It has been attempted by measuring the velocities of the shadows of clouds upon the surface of the earth ; but this method is very fallacious : first, because it is not known whether the clouds do or do not move exactly with the air in which they float ; and secondly, because the velocity of the air at the region where the clouds are, is by no means the same as that of the air which is nearer to the surface of the earth, and sometimes is quite contrary to it, which is indicated by the motion of the clouds themselves.

The best method of measuring the velocity of the wind is by observing the velocity of the smoke of a low chimney, or to estimate it by the effect it produces upon certain bodies.

IV. Whatever has been said in Chap. IV. of the present Second Part of these Elements, is so evidently

dently applicable to the impulse which air in motion gives to solids, or to the obstruction which solids receive in their movements through air; that it would be needless in this place to dwell any longer upon the theoretical part of the subject.

The best method of estimating the force as well as the velocity of the wind, is from the effects which it produces upon certain bodies. The instruments which have been found to answer these purposes in the best manner, will be described hereafter; but for the present we shall observe, that from the concurrence of the experiments which have been made with various instruments and different methods, the following estimate has been deduced; namely, that in currents of air of the denominations which are expressed in the fourth column of the following table, the air moves at the rate of so many feet per second as are expressed in the second column, or of so many miles per hour as are expressed in the first column. The third column expresses in avoirdupoise pounds, the force of the wind on an area of one foot square, which is presented in a direction perpendicular to it.

This table was first published in the 51st volume of the Philosophical Transactions, by Mr. J. Smeaton, the celebrated engineer, who, in his valuable Paper on the natural powers of water and wind, introduces it with the annexed paragraph.

" The following table, which was communicated to me by my friend Mr. Rouse, and which ap-

" pears

reasons which are easily derived from the theory of the resolution and composition of forces, and from the theory of direct and oblique impulses which have been delivered in the First Part of these Elements; also from what has been said in the IVth Chapter of this Second Part. In short, the general proposition for compound impulses is, that — *The effective impulse is as the surface, as the square of the air's velocity, as the square of the sine of the angle of incidence, and as the sine of the obliquity of the solid's motion to the direction of the impulse, jointly;* for the alteration of every one of those quantities will alter the effect in the same proportion. But those general rules, as we have already more than once observed, are subject to great variations; so that their results seldom coincide with those of actual experiments. In the motion of solids through air, a great retardation arises (besides other causes) from the condensation of the air before the solid, and from the rarefaction, and, with some velocities, the vacuum, which is formed behind the solid; hence nothing but actual experiments can possibly illustrate this subject\*. Winds

\* See Derham's Paper on the Velocity of Sound. Philosophical Transactions Abridged, vol. IV. Robins's Treatise on Gunnery. De Borda's Experiments, in the Memoirs of the Academy of Sciences for 1763. Smeaton's Paper in the Philosophical Transactions, vol. 51st. But a great many more experiments must be instituted by scientific persons before the subject can be sufficiently elucidated.

are of great use to us; but in the application of the winds to navigation, to wind-mills, and to other machines, some other circumstances must likewise be had in view; namely, the probable force, duration, and direction, of the wind which is likely to blow in any given place. These particulars must be derived from the history of countries, or from meteorological journals, viz. from long and accurate experience.

It appears that almost in all exposed situations, such as the open sea, extensive plains, tops of hills, &c. the wind almost always prevails; and few indeed are the days, or the hours, throughout the year, in which a real, or what is called a dead, calm is to be observed.

In those places for more than three quarters of the year (I do not mean without interruption) the force of the wind is sufficient to work a nicely made wind-mill, or at least to impel the sails of a ship.

The wind machines of larger size and greater power, which are applied to pumps for extracting water from deep pits, which are applied to the grinding of hard materials, &c. require a higher wind to put them in motion. Dr. Stedman was informed by a gentleman of experience, who had erected a wind-machine to drain his coal-pit, that he never could depend upon more than 53 or 54 hours of wind sufficient for moving that machine in a week, taking the year round. Dr. Stedman him-

self, from a careful inspection of a column for the wind in a meteorological journal, endeavoured to form a proportion between the duration of wind of a certain degree, and that of another degree.

"From this computation," he says, "we have  
" 2,592 days in a week, or 19,307 weeks in a  
" year, in which wind machines of the heavier  
" kind, and of considerable friction, may be sup-  
" posed to be kept in motion; which, to the times  
" wherein they cannot go, is as 10 to 17."

But the journal upon which he grounded his proportion, was the journal of a single place; the period of years, as he justly observes, was too short; the proportion for the different months of the same name in different years, as also the proportion for the different years, as appears from the tables he has given, are too fluctuating and irregular; to which we may add, that the meteorological journals in general, wherein one or two observations are stated for every 24 hours, do not afford materials sufficient for an accurate estimate\*.

The direction of the wind, which is various in most countries, and varies in the same country, acquires its different denominations from the four principal quarters, or cardinal points of the world. Thus it is called *North wind*, when it blows from the north towards the south; it is called *East wind*,

\* See Dr. Stedman's Paper in the 67th volume of the Philosophical Transactions.

when it blows from the east towards the west ; it is called *South wind*, when it blows from the south towards the north, and *West wind*, when it blows from the west towards the east.

The winds which deviate a little from the cardinal points, are commonly called *norterly*, *easterly*, *southerly*, and *westerly*, winds. But for the sake of greater distinction, the space or arch which lies between any two contiguous cardinal points, is supposed, by the mariners, to be divided into eight equal parts, or *points*, and each point into four equal parts, called *quarter-points*. So that the horizon is supposed to be divided into 32 principal points, which are called *rbumbs*, or *winds*, to each of which a particular name is assigned ; and those names are derived from the names of the adjacent cardinal points, as is shewn by the following table, wherein the names of all the 32 points are arranged in order from the north, eastward, &c. but those names are generally expressed simply by their initials. Thus, N. stands for north ; S. E. stands for south-east, &c.

North

North by East

North North East

North East by North

North East

North East by East

East North East

East by North

East

East by South

East South East

South East by East

South East

South East by South

South South East

South by East

South	West
South by West	West by North
South South West	West North West
South West by South	North West by West
South West	North West
South West by West	North West by North
West South West	North North West
West by South	North by West.

Almost in every country, the wind is more or less predominant in a particular direction; but before we begin to enumerate the observations which have been made relatively to those directions, it will be proper to mention the causes, which, as far as we know, produce the wind, in order that the reader may be enabled in some measure to comprehend the reasons of the particular directions, which will be mentioned in the sequel.

Heat, which rarefies, and cold which condenses, the air, are by far the principal, and more general, causes which are productive of a current of air; and the greatest general heat or cold is derived from the presence or absence of the sun.

The next cause has been justly attributed to the attraction of the sun and moon, whose influence is supposed, with great probability, to occasion a tide, or flux and reflux, of the atmospherical fluid, similar to that of the sea, but greater, because the air lies nearer to those celestial bodies, and because air is incomparably more expansible than water.

It has been calculated by D'Alembert from the general theory of gravitation, that the influence of sun and moon in their daily motions, is sufficient to produce a continual east wind about the equator. So that upon the whole we may reckon three principal daily tides, viz. two arising from the actions of the sun and moon, and the third from the heat of the sun alone: all which sometimes combine together, and form a prodigious tide.

In corroboration of the opinion of the influence of the sun, and principally of the moon, in the production of wind, we must likewise mention the observations of Bacon, Gassendi, Dampier, Halley, &c. namely, that the periods of the year most likely to have high winds, are the two equinoxes; that storms are more frequent at the time of new & full moon, especially those new and full moons which happen about the equinoxes; that, in periods otherwise calm, a small breeze takes place at the time of high water; and that a small movement in the atmosphere is generally perceived a short time after the noon and the midnight of each day.

Some action in the production of wind may also be derived from volcanoes, fermentations, evaporation, and especially from the condensation of vapours: for we find that, in rainy weather, a considerable wind frequently precedes the approach of any single cloud, and that the wind subsides as soon as the cloud has passed over our zenith.

Wherever any of the above-mentioned causes is

constantly more predominant, as the heat of the sun within the tropics, there a certain direction of the wind is more constant; and where different causes interfere at different and irregular periods, as in those places which are considerably distant from the torrid zone, there the winds are more changeable and uncertain.

In short, whatever disturbs the equilibrium of the atmosphere, viz. the equal density or quantity of air at equal distances from the surface of the earth; whatever accumulates the air in one place, and diminishes it in other places, must occasion a wind both in disturbing and in restoring that equilibrium\*.

Those general observations seem to agree tolerably well with the following facts, which have been ascertained by the concurring testimony of skilful seamen, and other observers.

i. Between the limits of 30°. north and 30°. south latitude, there is a constant, or almost constant, easterly wind, blowing, but not violently, at all times of the year, in the Atlantic and Pacific oceans. This is called the *trade wind*.

\* Mr. Brisson is of opinion that electricity is the principal and more general cause which produces winds: "j'amerois mieux," he says, "donner pour cause première et générale des vents, l'électricité, qu'on sait qui règne continuellement dans l'atmosphère, et à la surface de notre globe." *Principes de Physique*, § 1035.—I am by no means of the same opinion.

Towards the middle of the above-mentioned tract of about  $60^{\circ}$ . viz. about the equator, the wind blows either exactly from the east, or very little distant from that point; but on the borders of the above-mentioned space, the wind deviates from that point, viz. near the northern limit the trade-wind blows from between the north and the east, and near the southern limit, it blows from between the south and the east.

The trade-wind seems to depend principally upon the rarefaction of the air, which is occasioned by the heat of the sun progressively from the east towards the west. The air which is rarefied, and, of course, elevated by the heat of the sun immediately over it, is condensed and descends, as soon as the sun is gone over another place to the west of the former; then the air of the latter place is rarefied, and the condensed air of the former rushes towards it, &c. From the northern and southern parts of the world, the air likewise runs to the place which is immediately under the sun; but those directions, combining with the easterly wind, which blows nearer to the equator, form the above-mentioned north-easterly and south-easterly winds on the borders of the trade-wind.

2. In places that are farther from the equator, the rarefaction which arises from the heat of the sun, and from the attraction of the sun and moon, is less active; and is besides influenced by a variety of local and accidental circumstances, such as ex-

tensive continents, mountains, rains, islands, &c. which disturb, interrupt, or totally change the direction of the wind. Hence, in those latitudes north and south, which are beyond the limits of the trade-wind, or near the coasts, the winds are very uncertain; nor has any good theory been as yet formed respecting them: I shall, however, proceed to enumerate the facts which have been ascertained, and to mention the most plausible elucidations of the causes upon which they may depend\*.

3. In some parts of the Indian ocean there are winds which blow one way during one half of the year, and then blow the contrary way during the other half of the year. Those winds are called *Monsoons*, and are explained in the following manner.

It is said, that as the air which is cool and dense, will force the warm rarefied air in a continual stream upwards, there it must spread itself to preserve the equilibrium. Therefore the upper course or current of air must be contrary to the under current; for the upper air must move from those parts where the greatest heat is; and so, by a kind of circulation, the N.E. trade-wind below will be attended with a S.W. above; and a S.E. below, with a N.W. above.

\* Those particulars have been collected principally by Mr. Robertson. See his Elements of Navigation, B. VI. Sect. VI.

4. In the Atlantic ocean, near the coasts of Africa, at about 300 miles from the shore, between the north latitudes of  $10^{\circ}$ . and  $28^{\circ}$ . seamen constantly meet with a fresh gale of N.E. wind.

5. Across the Atlantic ocean, on the American side of the Caribbee islands, it has been observed, that the above-mentioned N. E. wind becomes easterly, or seldom blows more than a point from the east on either side of it.

6. These trade winds on the American side are often extended as far as the  $32^{\circ}$  degree of N. latitude, which is about  $4^{\circ}$  farther than their extension on the African side. Also, on the south-side of the equator the trade winds extend  $3^{\circ}$ , or  $4^{\circ}$  farther towards the coast of Brasil on the American side, than they do near the Cape of Good Hope, or African side.

7. Between the latitudes of  $4^{\circ}$ . N. and  $4^{\circ}$ . S. the wind always blows between the south and east. On the African side the winds are nearest to the south; and on the American side, nearest to the east. In these seas Dr. Halley observed, that when the wind was eastward, the weather was gloomy, dark, and rainy, with hard gales of wind; but when the wind turned to the southward, the weather generally became serene, with gentle breezes approaching to a calm. These winds are somewhat changed by the seasons of the year; for when the sun is far northward, the Brasil S.E. wind gets to the scut'i, and the N.E. wind to the E.; and when

when the sun is far south, the S. E. wind gets to the E. and the N.E. wind on this side of the equator goes more towards the north.

8. Along the coast of Guinea, from Sierra Leon to the island of St. Thomas (under the equator) which is above 1500 miles, the southerly and south-west winds blow perpetually. It is supposed that the S.E. trade-wind, having passed the equator, and approaching the guinea coast within 240 or 300 miles, inclines towards the shore, and becomes S., then S.E., and gradually, as it comes near the land, it inclines to south, S.S.W. and close to the land it is S.W. and sometimes W.S.W.—This tract is subject to frequent calms, and to sudden gusts of wind called *tornadoes*, which blow from all points of the horizon.

The westerly wind on the coast of Guinea is probably owing to the nature and situation of the land, which being greatly heated by the sun, rarefies the air exceedingly; hence the cooler and heavier air from over the sea will keep rushing in to restore the equilibrium.

9. Between the latitudes of  $4^{\circ}$  and  $10^{\circ}$  north, and between the longitudes of Cape Verd, and the eastermost of the Cape Verd Isles, there is a tract of sea, which seems to be condemned to perpetual calms, attended with terrible thunder and lightnings, and such frequent rains, that this part of the sea is called *the Rains*. It is said that ships have some-

times been detained whole months in sailing through these six degrees.

The cause of this seems to be, that the westerly winds setting in on this coast, and meeting the general easterly wind in this tract, balance each other, and cause the calms ; and the vapour carried thither by the hottest wind, meeting the coolest, is condensed, and occasions the very frequent rains.

10. Between the southern latitudes of  $10^{\circ}$ . and  $30^{\circ}$ . in the Indian ocean, the general trade-wind about the S.E. by S. is found to blow all the year long in the same manner as in the like latitude in the Ethiopic ocean : and during the six months from May to December, these winds reach to within two degrees of the equator ; but during the other six months, from November to June, a N.W. wind blows in the tract lying between the latitudes of  $3^{\circ}$ . and  $10^{\circ}$ . south, in the meridian of the north end of Madagascar ; and between the latitudes of  $2^{\circ}$ . and  $12^{\circ}$ . south, near the longitude of Sumatra and Java.

11. In the tract between Sumatra and the African coast, and from  $3^{\circ}$  of south latitude quite northward to the Asiaestic coasts, including the Arabian sea and the gulf of Bengal, the Monsoons blow from September to April on the N.E. and from March to October, on the S.W. In the former half-year the wind is more steady and gentle, and the weather clearer than in the latter half-year.

Also

Also the wind is stronger and steadier in the Arabian sea than in the gulf of Bengal.

12. Between the island of Madagascar and the coast of Africa, and thence northward as far as the equator, there is a tract, in which, from April to October, there is a constant fresh S. S.W. wind, which to the northward changes into the W.S.W. wind, blowing at the same time in the Arabian sea.

13. To the eastward of Sumatra and Malacca on the north side of the equator, and along the coasts of Cambodia and China, quite through the Philippines as far as Japan, the Monsoons blow northerly and southerly; the northern setting in about October or November, and the southern about May. These winds are not quite so certain as those in the Arabian sea.

14. Between Sumatra and Java to the west, and New Guinea to the east, the same northerly and southerly winds are observed; but the first half-year Monsoon inclines to the N.W. and the latter to the S.E.—These winds begin a month or six weeks after those in the Chinese seas set in, and are quite as variable.

15. These contrary winds do not shift from one point to its opposite all at once. In some places the time of the change is attended with calms, in others with variable winds. And it often happens on the shores of Coromandel and China, towards the end of the Monsoons, that there are most violent storms,

greatly resembling the hurricanes in the West Indies, when the wind is so vastly strong, that hardly anything can resist its force.

16. The irregularities of the wind in countries which are farther from the equator than those which have been mentioned above, or nearer to the poles of the earth, are so great that no particular period has as yet been discovered, excepting that in particular places certain winds are more likely to blow than others. Thus at Liverpool the winds are said to be westerly for near two thirds of the year; in the southern part of Italy a S. E. wind (called the *schirocco*) blows more frequently than any other wind, &c.

17. The temperature of a country with respect to heat or cold, is increased or diminished by winds, according as they come from a hotter or colder part of the world. The north and north-easterly winds, in this country and all the western parts of Europe, are reckoned cold and drying winds. They are cold because they come from the frozen region of the north pole, or over a great tract of cold land. Their drying quality is derived from their coming principally over land, and from a well known property of the air, namely, that warm air can dissolve, and keep dissolved, a greater quantity of water than colder air: hence the air which comes from colder regions being heated over warmer countries, becomes a better solvent of moisture, and dries up with greater energy the moist

moist bodies it comes in contact with ; and, on the other hand, warm air coming into a colder region deposits a quantity of the water it kept in solution, and occasions mists, fogs, clouds, rains, &c. " In short," says Col. Roy, " the winds seem to be drier, denser, and colder, in proportion to the extent of land they pass over from the poles towards the equator ; but they appear to be more moist, warm, and light, in proportion to the extent of ocean they pass over from the equator towards the poles. Hence the humidity, warmth, and lightness, of the Atlantic winds to the inhabitants of Europe. On the east coasts of North America the severity of the N. W. wind is universally remarked ; and there can scarcely be a doubt, that the inhabitants of California, and other parts on the west side of that great continent, will, like those on the west of Europe, feel the strong effects of a N. E. wind."

18. In warm countries sometimes the winds, which blow over a great tract of highly heated land, become so very drying, scorching and suffocating, as to produce dreadful effects. These winds under the name of *Solanos*, are often felt in the deserts of Arabia, in the neighbourhood of the Persian gulph, in the interior of Africa, and in some other places\*. There are likewise in India, part

\* See the Abbé Richard's Nat. Hist. of the Air and Meteors.

of China, part of Africa, and elsewhere, other winds, which deposit so much warm moisture as to soften, and actually to dissolve glue, salts, and almost every article which is soluble in water.

19. It is impossible to give any adequate account of irregular winds, especially of those sudden and violent gusts as come on at very irregular periods, and generally continue for a short time. They sometimes spread over an extensive tract of country, and at other times are confined within a remarkably narrow space. Their causes are by no means rightly understood, though they have been vaguely attributed to peculiar rarefactions, to the combined attractions of the sun and moon, to earthquakes, to electricity, &c. They are called in general *burricanes*, or they are the principal phenomenon of a hurricane, that is, of a violent storm.

Almost every one of those violent winds is attended with particular phenomena, such as droughts, or heavy rains, or hail, or snow, or thunder and lightning, or several of those phenomena at once. They frequently shift suddenly from one quarter of the horizon to another, and then come again to the former point. In this case they are called *tornadoes*.

Several years ago some general characters or prognostics of hurricanes were collected by Capt. Langford, which seem not to have been materially contradicted by subsequent observations. See his Paper in the Philosophical Transactions Abridged, vol.

vol. II. p. 105, from which I have transcribed the following five paragraphs.

“ All hurricanes come either on the day of the full, change, or quarter of the moon.”

“ If it will come on the full-moon, you being in the change, then observe those signs.”

“ That day you will see the skies very turbulent, the sun more red than at other times, a great calm, and the hills clear of clouds, or fogs, &c.”

“ It is to be observed, that all hurricanes begin from the north to the westward, and on those points that the easterly wind doth most violently blow, doth the hurricane blow most fiercely against it; for from the N. N. E. to the E. S. E. the easterly wind bloweth freshest; so doth the W. N. W. to the S. S. W. in the hurricane blow most violent; and when it comes back to the S. E. which is the common course of the trade-wind, then it ceaseth of its violence, and so breaks up.”

“ In a tornado, the winds come on several points. But before it comes it calms the constant easterly winds; and when they are past, the easterly wind gathers force again, and the weather clears up fair.”

Those observations were intended for places within, or not far from the torrid zone, and principally for the West-India islands, which are frequently visited by hurricanes.

20. When the gusts of wind come from different quarters at the same time, and meet in a certain place, there the air acquires a circular, or rotatory, or screw-like motion, either ascending or descending, as it were, round an axis, and this axis sometimes is stationary, and at other times moves on in a particular direction. This phenomenon, which is called a *whirlwind*, gives a whirling motion to dust, sand, water, part of a cloud, and sometimes even to bodies of great weight and bulk ; carrying them either upwards or downwards, and lastly scatters them about in different directions.

The *water spout* has been attributed principally, if not entirely, to the meeting of different winds. In that case the air in its rotation acquires a centrifugal motion (see p. 138 of part I.); whence it endeavours to recede from the axis of the whirl, in consequence of which a vacuum, or, at least, a considerable rarefaction of air, takes place about the axis, and, when the whirl takes place at sea, or upon water, the water rises into that rarefied place ; for the same reason which causes it to ascend into the exhausted tube (see page 205 of this part), and forms the water-spout or pillar of water in the air : yet the various appearances of water spouts do not seem to be quite reconcilable to the above mentioned theory.—Some ingenious persons have considered the water spout as an electrical phenomenon ; having observed, that thunder clouds and

lightnings have been frequently seen about the places where water spouts appear, and likewise that by means of artificial electricity, a water spout may in some measure be imitated. But it must be observed, that the lightning and other electrical phenomena appear to be rather the necessary consequence than the cause, of the water spout ; it being well known that electricity is produced whenever water is reduced into vapour, or vapour is condensed into water. We shall, however, examine this particular in another part of these elements.

The following are the most remarkable facts relative to water spouts.

Two, or three, or more, water spouts are frequently seen within the space of a few miles, and they are mostly seen at sea.

Their size is various, not exceeding, however, a few feet in diameter ; and the same water spout sometimes increases and decreases alternately ; it also appears, disappears, and reappears, in the same place.

The water spout sometimes proceeds a little way from a cloud, or a little way from the sea ; and often those two short and opposite spouts are not only directed towards each other, but they are extended and meet each other.

When it proceeds from the sea, the water about the place appears to be much agitated, and rises a

\*

short

short way in the form of a jet or spray, or steam, in the middle of which a thick, well defined, and generally opaque, body of water rises, and proceeds to a considerable height into the atmosphere, where it is dissipated into a vapour, or it seems to form a cloud.

When it proceeds from a cloud, the clouds about the spot frequently appear much agitated, and an agitation of the water immediately under the spot is generally seen at the same time.

The water spout is frequently seen to have a spiral or screw-like motion, and sometimes is attended with considerable noise.

Some of them stand in a perpendicular direction, others are inclined, and some water spouts form a curve, or even an angle.

The water spouts generally break about their middle, and the falling waters occasion great damage, either to ships that have the misfortune of being under them, or to the adjoining land; for such spouts are sometimes formed on a lake, or river, or on the sea close to the land.

Sometimes the water spouts are seen where there is no appearance of whirlwind, or where the wind (at least to a spectator at some distance) appears to blow regularly one way.

The oblique spouts almost always point from the wind; for instance, when the wind is N.E. the spout will point to the S. W. fig. 20. of

Plate XIII. represents a water spout of the most complete form\*.

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- Several particular accounts of water spouts may be seen in various volumes of the Philosophical Transactions, especially in the 4<sup>th</sup> volume of Jones's Abridgment. Also in Franklin's Miscellaneous Papers; in almost all the accounts of voyages; and in most works upon Electricity.

## CHAPTER XI.

## OF SOUND, OR OF ACOUSTICS.

THE sensation, which we perceive through the organ of hearing, is called *sound*; such the sound of a human voice, or of the voices of other animals; as the sound of a bell, or of the stroke a hammer, of the wind amongst trees, or of singing water, of an organ, &c.

The science which treats of sound in general is called *acoustics* (from the Greek verb for *bearing*) *phonics* (from the Greek word which means a *noise* or *sound*). And most of the other terms which are used in treating of sound, are derived from the above-mentioned words; such as *diacoustics*, viz. of refracted sound; *catacoustics*, viz. reflected sound, or of the *echo*; *otacoustics*, viz. of means of improving the sense of hearing, as by means of the hearing trumpet, &c.

The body which produces the sound is called the *sonorous body*, or *sounding body*; and whilst sound, the sonorous body is evidently, and unquestionably, in a state of vibration.

Air is the only substance which, in common, tends to exist between sonorous bodies and our ears; and it has been observed that, *ceteris paribus*, the sound of the very same sonorous body, such

as a bell, a drum, &c. is louder or more powerful, and may be heard farther, where the air is denser, as in vallies, than where the air is less dense, as on the tops of high mountains. Therefore we are led to conclude that air is the vehicle of sound, viz. that the sonorous body communicates a vibratory motion to the surrounding air, which motion is gradually communicated from the air next to the sounding body, to that which is more distant from it, somewhat like the waves upon the surface of water; until that vibratory motion is communicated to the sensible part of the ear. But sound is likewise conveyed by other bodies, both solid and fluid; as will be shewn in the sequel.

Infinite is the variety of sounds; for a manifest difference is to be perceived between the voices of any two human beings, or between the voices of other animals; and persons who have accustomed their ears to nice discriminations, can distinguish a difference between the sounds of very similar musical instruments, viz. such as are constructed, tuned and struck, to all appearance, perfectly alike.

The variety of sounds arises from three causes principally, viz. 1st, from the greater or less frequency of the vibrations of the sonorous bodies; 2dly, from the quantity, force, or momentum of the vibrating particles which strike the ear; and 3dly, from the greater or less simplicity of the sounds.

Hence

Hence are derived the *height*, the *strength*, and the *quality* of a sound.

1. If you strike the string of a musical instrument, then stop that string in the middle, and strike one half of it only, or stop any part of it, and strike the other part, the short part will perform quicker vibrations, or what is called a higher tone, than the whole string; so that the frequency of the vibrations produces *high* or *low*, *acute* or *grave*, *sharp* or *flat*, sounds; for the more frequent the vibrations are, the higher, or more acute, or sharper, is the sound said to be, and *vice versa*.

2. The strength of sound arises from the space through which the vibrating parts move, or from the length of the vibrations; it is also owing to reflection. The vibratory motion of a sounding body is communicated spherically all round the body, and of course, like other emanations from a centre, is gradually diminished in intensity, according to the distance (see page 62. Part I.)\*.

\* The decay of sound, or the diminution of its intensity, has been supposed by D. Bernoulli, De la Grange, and others, to be nearly in the direct ratio of the distances. But other ingenious persons have supposed it to be nearly as the squares of the distances. Their reasonings and calculations are established on different principles; but all the particulars which should be taken notice of in this calculation, are by no means known; nor do we know of any practical method of measuring the intensity of sound.

But if that communication be prevented on certain sides, and be permitted to take place on a particular side only ; or if the vibrations which are communicated by the same sonorous body to different bodies, be reflected from the latter to a particular place ; the sound will be heard in that place much louder than otherwise. Hence arises the effect of the *speaking trumpet*, or *stentoropbonic tube*\* ; hence

\* In a speaking trumpet the sound in one direction is supposed to be increased, not so much by its being prevented to spread all round, as by the reflection from the sides of the trumpet. But as the real action of the instrument, or the true motion of the air through it, is not clearly understood; different persons, according to their particular conceptions of the case, have recommended peculiar shapes for the construction of such trumpets ; some having recommended a conical shape, others that which is formed by the rotation of certain curves round their axes ; others again have recommended an enlargement or two of the cavity in the length of the trumpet, &c. That which has been more commonly recommended as the best figure for such trumpets, is generated by the rotation of a parabola about a line parallel to the axis.

A speaking trumpet of the shape mostly used by navigators, is represented at fig. 15. Plate XIII. It is an hollow instrument of copper or of tinned iron-plates. It is open at both ends; and the narrow end, A, is shaped so as to go round the speaker's mouth, and to leave the lips at liberty within it. The edge of this narrow end is generally covered with leather or cloth, in order that it may more effectually

hence the effect of what are called *whispering galleries*, or *whispering domes*; hence the sound of a bell, or the report of a pistol in a room, produces a much stronger effect upon our ears than in the open air, &c.

3. A sounding body vibrates in more directions than one; for instance, if a body of irregular shape or size be struck, the thin parts of it will perform their vibrations in different times from those in

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actually prevent the passage of any air between the trumpet and the face of the speaker. When a person applies his mouth to the narrow end, and, directing the tube to a particular place, speaks in it; the words may be heard much farther and much louder in the direction of the trumpet, by persons who are before it, than they would without the trumpet. A person who is not in the direction of the trumpet will hear the sound of it both weaker and less distinct, in proportion as he is more or less distant from the direction of the sound; which is the direction straight before the trumpet.

The words which are spoken through a speaking trumpet may be heard much farther and louder, but not so distinctly, as without the trumpet.

A speaking trumpet has also been applied to the mouth of a gun or pistol, by which means the explosion has been rendered audible at a vast distance.—Such contrivances may be used as signals in certain cases.

See the description of some particular shapes of speaking trumpets in the Philosophical Transactions, No. 141, or Lowthorp's Abridgment, vol. I. page 505.

which

which the thicker parts perform their vibrations; hence arise different sounds from the same body at the same time; and those different sounds are greater in number and quality, according to the irregularities of the sounding body. The more uniform the sounding body is in shape and quality, the simpler, more uniform, and more pleasing its sound is; but probably there is no sounding body in nature, which emits a single sound. However, when the sounding body emits one predominant sound, and the concomitant sounds are barely distinguished, then that predominant sound may be considered as a *simple sound*.

From the combination of the above-mentioned three causes, the various sounds derive their denominations of *big*, *low*, *weak*, *barsb*, *clear*, *rough*, *smooth*, *pleasant*, *unpleasant*, *confused*, &c.

The human voice is capable of expressing the greatest variety of sounds.

The vibratory motion of a sounding body will continue for a longer or shorter time after the stroke which causes it to vibrate, according as that body is more or less elastic; as it is thicker or thinner, &c.

This vibratory motion, especially when the sounding bodies are large and powerful, as a large bell, a large string of a musical instrument, and such like, is generally apparent to the naked eye; but it may be rendered still more manifest by bringing a finger, or other solid, very near their surfaces.

When

When a string of uniform shape and quality is stretched between, and is fixed to, two steady pins, as A, B, fig. 16, of Plate XIII. if it be drawn out of its natural, or quiescent, position AB, into the situation ACB, and if then it be let go, it will, in consequence of its elasticity, not only come back to its position AB; but it will go beyond it, to the situation ADB, which is nearly as far from AB, as ACB was on the other side, and all this motion one way is called one vibration; after this, the string will go again nearly as far as C, making a second vibration; then nearly as far as D, making a third vibration, and so on; diminishing the extent of its vibrations gradually, until it settles in its original position AB.

It seems natural that the air, which is contiguous to the sounding body, must receive the like vibratory motion, viz. it must be caused to perform vibrations of equal duration with those of the sounding body; and those vibrations, being spread successively through the air, in their course, reach our ears, and communicate to them the like vibrations, which excite in us the sensation of a particular sound.

The air communicates the above-mentioned vibrations not only to the organs of hearing; but likewise to other solids in certain circumstances, viz. to such solids as, if struck, would emit a sound which is either exactly like, or bears some analogy to, that of the original sounding body. Thus let the string

of

of a violin be tuned exactly like a similar string of another violin ; so that if either of them be struck, the same sound may be heard. Place a little bit of paper upon the string of one of the violins, about the middle of it, and place that instrument upon a table ; let the other violin be held near it, for instance, within a foot or two, and in that situation strike the above-mentioned string of the latter violin. It will be found that whilst this is sounding, the corresponding string of the other violin upon the table, will evidently vibrate, as is manifested by the bit of paper upon it.

In short, it has been generally observed, that if of two strings, or of two other sonorous bodies, which are capable of performing their vibrations in equal times, one only be caused to sound, the other string or other sonorous body will also be found to vibrate, provided it be not too far from the first mentioned sonorous body.

The same thing, though not in an equal degree, will take place if one of the sonorous bodies be capable of performing two, or three, or four complete vibrations, whilst the other is capable of performing one vibration only, and either of them is caused to sound.

If one of the strings which is put in motion, performs three vibrations, whilst another string, which is to be set a vibrating by the sound of the first, can perform only one vibration with its whole length; then this last string will divide itself into three vi-

brating

brating parts, and there will be two points at rest, as may be seen by placing bits of paper or other light bodies upon different parts of the latter string.

This shews that the vibrations of the sounding body are communicated to the air, and by the air to the other sonorous body. It shews likewise, that the vibrations of the air must be performed in the same time as those of the sounding body\*.

The

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\* A string, or a body capable of being put in a state of vibration, as a pendulum at rest, may be caused to vibrate by the repeated application of the least impulse, provided those impulses be repeated at the expiration of such portions of time as the pendulum, or other body, would perform every two of its vibrations; for instance, if a pendulum, when put in motion, would perform each vibration in one second, and of course it would come to the same side every other second; then if, when such a pendulum is at rest, you give it an impulse ever so little (even a puff of air from your mouth) at the end of every two seconds; the pendulum will soon be seen to vibrate. The reason of which is, that from the law of collision, (see page 42 of Plate I.) since every impulse must produce a proportionate effect, the first impulse must cause the pendulum to move a little out of the perpendicular, or to perform a short, and perhaps an invisible, vibration; and if no other impulse were given, the pendulum would by itself (see page 174 of P. I.) perform another vibration shorter than the first, then another still shorter, and so on; but by giving it the second impulse at the end of the proper time, the effect of that impulse, conspiring with the natural motion of the pendulum, will enable

The surface of water is agitated a little by the sound of a large bell, or the report of canon. Windows, wainscots, &c. are frequently caused to vibrate by the sound of organs, and other large instruments.

The communication of the vibrations to the air is usually explained in the following manner.—Let the sonorous body be a string fastened to, and stretched between, two fixed pins ; (for whatever is said with respect to the vibrations of the string,

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it to perform a longer vibration than it could perform without it. By the same way of reasoning it will appear that the third impulse will increase the length of the vibrations still more, and so on.

If the impulse be repeated at the end of every 4, or every 6, &c. vibrations; the vibration of the pendulum will also be increased, and will at last become visible, but not so effectually as by the repetition of the impulse at every other vibration ; which is so evident as not to require any farther illustration.

If the impulses be repeated not at the proper intervals of time, then their action, instead of conspiring with the motion of the pendulum, will check the little motion which was communicated to it by the first impulse, and of course the vibration of the pendulum cannot be rendered visible.

Therefore, whenever we find that a certain body is caused to vibrate by the reiteration of a certain weak impulse, we may conclude that such impulse has been repeated at such intervals of time as the body is capable of performing two, or four, &c. of its vibrations.

may

may be applied to the vibration of other sounding bodies) and *a, b, c, d, &c.* be a row of aerial particles on one side, and in the direction of the vibrations of the string. When this string is caused to vibrate, the first vibration will drive the particle *a*, towards *b*, and of course *b* must impel *c* towards *d*, &c. but whilst the motion is thus communicated from one particle to the next, the string goes back towards the axis, or performs its second vibration. This removes the pressure from *a, b, &c.* and besides the string, by its quick motion, occasions a rarefaction at the place where a little before it had caused a condensation, in consequence of which the particles *a* and *b* will recede a little way from each other, and this expansion will gradually proceed through the adjoining particles; then again another condensation on that side takes place, &c. Thus the successive waves or shells of condensed and rarefied air follow each other.

The best way of explaining the crossing of various sounds, or of the vibrations which arise from several sounds at the same time, may perhaps be by supposing, that the air partakes of all the various vibrations; somewhat like the crossing of the waves of water (see p. 158.); viz. that each shell of condensed and rarefied air, which is the consequence of one sound, is itself alternately condensed and rarefied in another direction, in consequence of a second sound, &c.

The vibration of the air cannot be ocularly perceived,

ceived, except in an imperfect manner by the very small motion of the particles of dust, smoke, &c. which are seen to float in the air in certain lights, and which are made to vibrate in a small degree by the powerful sound of a large sonorous body.

But the explanation of the vibration of a stretched string, which we have given above in a simple manner for the sake of perspicuity, is far from being accurate and complete. In the first place it is easy to perceive that the string, A B, fig. 16. Plate XIII. must be longer when it stands in the situation A C B, or A D B, than when it stands straight between A and B; therefore it appears, that besides the lateral, there is also a longitudinal, vibration, which is capable of producing another sound, though not so powerful as that of the lateral vibration.

Secondly, the strings of musical instruments in their vibrations, especially at first, form curves somewhat different from each other, according to the different methods by which they are caused to vibrate, viz. whether they be struck in the middle, or close to one end; whether by the application of a finger, or a quill, or a bow, &c.\*

Thirdly,

\* The shapes which the same string assumes in its vibrations, after having been struck by different methods, may, in great measure, be perceived. "Take," says Dr. Young, "one of the lowest strings of a square piano forte, round  
"which

Thirdly, the string sometimes seems to divide itself into parts, viz. some parts of the string perform vibrations peculiar to their lengths at the same time that they partake of the general vibrations.

And, fourthly, a string seldom continues long to vibrate in one and the same plane; but the plane of its vibrations moves in different directions, which are far from being regular. This deviation of the plane of vibration from its original situation, may probably be owing to the obliquity of the impulse, or to the inequalities in the figure of the string, or to the resistance of the air, &c. This movement of the plane of vibration may be discerned by viewing a sounding string in the direction of its length.

If the movements of a stretched string be so complicated and uncertain, one may easily conceive the difficulty of comprehending, or of investigating,

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" which a fine silvered wire is wound in a spiral form; contract the light of a window; so that, when the eye is placed in a proper position, the image of the light may appear small, bright, and well defined on each of the convolutions of the wire. Let the chord be now made to vibrate, and the luminous point will delineate its path, like a burning coal whirled round, and will present to the eye a line of light, which, by the assistance of a microscope, may be very accurately observed." Phil. Trans. for 1800.  
page 135.

the movements of other sounding bodies, the greatest part of which are vastly more irregular in shape and quality than the stretched string.

The vibrations of the air, which are produced by the above-mentioned movements of the same sounding body, must evidently be very complicated and uncertain. Besides, even in the simplest mode of vibration, as that of the string; it is evident that the collapsing of the air behind it must occasion another sort of vibration, besides that which is produced on the fore part of the string. In short, it must be confessed, that the real motion of the air, or its various movements, in its conveyance of sound, are far from being rightly understood.

Most sonorous bodies not only perform different vibrations at the same time, but they may be caused to perform certain vibrations and not others, or they may be caused to vibrate at pleasure in certain directions more powerfully than in other directions; and that by the different manner of holding or striking them. Thus, if a glass, partially filled with water, be struck on the side, it will emit one sound, and if, instead of that, you rub your wet finger over the edge of it, you will perceive a different sound.

Most oblong and elastic bodies may be caused to vibrate longitudinally by means of proper friction in the direction of their length. They may be rubbed with the finger, or with any soft substance

over

over which some pounded rosin is spread. The best way of rubbing glass rods, is by means of a wet rag besmeared with fine sand\*.

The sounds which arise from the longitudinal vibrations of sonorous bodies, are considerably higher than those which are produced by the lateral vibrations of the same bodies. The former agree with the latter in this, viz. that they are higher or lower inversely as the lengths of the sonorous body; but otherwise a very striking difference is to be remarked between the production of the former and that of the latter; namely, that the production of the latter depends upon the length, weight, and tension of the string or other sonorous body: whereas the former depend more upon the quality or nature of the sonorous body, than upon its thickness and weight. "I have examined," says Dr. Chladni, "every substance which I could obtain in a sufficiently long rod-like form, in regard to longitudinal vibration; for example, many kinds of wood and metal, also glass, whalebone, &c. The specific gravity

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\* Dr. Chladni of Wittemberg, who has made a very great number of experiments on the longitudinal vibrations of elastic bodies, lately contrived a musical instrument, which he calls the *euphon*, and which consists of glass rods disposed in a proper frame, which express their sounds by being rubbed longitudinally. A short account of this instrument may be seen in the Phil. Mag. vol. II. p. 391.

" makes no difference; for fir-wood, glass, and  
 " iron, give almost the same tone, as also brass,  
 " oak, and the shanks of tobacco-pipes made of  
 " clay\*."

Different bodies are more or less sonorous; but that property does not seem to be entirely dependent, either upon their specific gravity, or their tenacity, or even their elasticity. Copper seems to be the most sonorous of the simple metals, then comes silver, then iron, tin, platina, gold, and, lastly, lead, which seems to be the least sonorous metallic substance.

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\* Dr. Chladni has rendered, in great measure, apparent the different sorts of vibration, or rather the different parts of flat sonorous bodies, which are caused to vibrate by peculiar managements.—His method is briefly as follows :

If you take a pane of glass, or a thin metallic plate, or a piece of board, &c. and strew very light bodies, such as fine sand, over it. Then, holding it horizontally between your finger and thumb, you rub a violin bow across the edge of the plate; you will find that part of the plate is thereby caused to vibrate, as will be shewn by the motion of the sand; and by continuing the friction of the bow, you will perceive that the sand will be gradually removed from the vibrating parts, to those parts which do not vibrate.

By holding the plate in different places, and by applying two or more fingers to it, and then rubbing the bow across one part or another of the edge, the sand may be caused to assume different forms (called *vibration figures*) such as a circle, an ellipsis, a quadrangle, &c. See the Phil. Mag. vol. III. p. 389.

The

The communication of the vibrations from the vibrating part of a stretched string to some other part of it, which, at first sight, might be supposed to be at rest, is likewise attended with remarkable phenomena\*.

If you divide a string, as AD, fig. 17. Plate XIII. into three equal parts AB, BC, CD, by placing dots at C and B; place a bridge, like a violin bridge at B, also place light bodies, such as small bits of paper, at C, and at other places of the part BD; then draw a violin bow over the part AB; you will find that all the bits of paper will be thrown off from the part BD, excepting the one at C; shewing that the point C remains at rest, whilst the remainder of the string is vibrating.—This point, and all other points whereon, in such experiments, the bits of paper remain at rest, as also the point B, where the bridge is situated, are called *vibration nodes*.

Divide the string AB (fig. 18. Plate XIII.) by the points C, D, E, F, into five equal parts; intercept, by means of two bridges, the part DE; place small bits of paper upon C and F, as also upon other parts of the string; then rub the violin bow across the part DE, and you will find that all the bits of paper will be shaken, except those at C and F.

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\* See Voigt's Experiments, in Gren's *Journal de Phys.* vol. II. Part III.

Thus, by a proper division of the string, and by intercepting one or more aliquot parts of it, &c. any moderate number of vibration nodes may be exhibited\*. But it must be observed, that in those experiments, the communication of motion from the sounding part of the string, to the other, may be effected not so much through the substance of the string, as through the air. See p. 315.

In an organ pipe, and other wind instruments, it is not the instrument itself that principally vibrates; or rather the sound is produced by the vibration of the column of air within the pipe. In a large organ pipe this vibration of the column of air, which is somewhat longer than the pipe, may be felt by applying the open hand to the aperture of the pipe. But the particular manner in which this vibration is performed, is by no means rightly

\* The general rule for finding out the number of vibration nodes, according to any division of the string, is as follows :

Suppose the string to be divided into  $n$  number of parts, and that the portion, which is intercepted by the bridge or bridges, consists of  $m$  number of such parts; express the ratio of  $n$  to  $m$  in the lowest terms; subtract the latter from the former, and the remainder shews the number of vibration nodes. Thus, in the first example,  $n$  is equal to 3,  $m$  is equal to 1, and 1 being subtracted from 3, there remains 2; so that the vibration nodes are 2, viz. one at C, and the other at D.

understood.

understood.—The sound of the same pipe may be increased or diminished in quantity, or in acuteness, by supplying the pipe with different quantities of air, and by particular modes of blowing\*.

Upon the whole it appears, that, by certain managements, the height of a sound may be increased or diminished; and, by other managements, the strength and quality of the sound may be altered. Thus expert violin players pass the bow over the strings sometimes very close to the bridges of their violins; and, at other times, at a greater distance, or nearer to the middle of the strings: by which means, *ceteris paribus*, they actually produce different effects.

It also appears that every sound, even those of the simplest musical instruments, is accompanied with other inferior, secondary, or less audible, sounds; and those secondary sounds are heard more distinctly when the sounding bodies are large or powerful, and when the principal sound is grave and continuative, than otherwise.—Hereafter, in speaking of the sounds, or of the vibrations, of sounding bodies, we mean only the vibrations which produce the principal or predominant sound, unless the contrary be mentioned.

We shall now state the most useful facts and observations which have been established and made

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\* See Dr. Young's Experiments, Phil. Trans. for 1800.  
p. 121.

by various ingenious persons, concerning the velocity, intensity, communication, reflection, and other properties of sounds in general.

Sound is propagated successively from the sounding body, to the places which are nearer to it, then to those that are farther from it, &c.

A great many long and laborious calculations have been made by divers able philosophers and mathematicians, for the purpose of deducing the velocity of sound through the air, from the known weight, elasticity, and other properties of air; but the results of such calculations differ considerably from each other, as also from the results of actual experiments, which shews either that the calculations have been established upon defective principles, or that not all the concurring circumstances have been taken into the account. Therefore, without mentioning any thing farther with respect to those calculations, I shall immediately state the result of authentic and useful experiments.

Almost every body knows, that when a gun is fired at a considerable distance from him, he perceives the flash a certain time before he hears the report; and the same thing is true with respect to the stroke of an hammer, of an hatchet, with the fall of a stone, or, in short, with any visible action, which produces a sound or sounds. This time which sound employs in its motion through

through the common air, has been measured by various ingenious persons. The principal and more general method has been to measure (by means of a stop watch or a pendulum) the time which elapses between the appearance of the flash, and the hearing of the report of a gun fired at a certain measured distance from the observer; for light travels so fast through the distance of 1000, or 2000 miles, that we cannot possibly perceive the time; therefore we may conclude that the explosion of a gun takes place at the very same moment in which we perceive the flash.

In the first place it has been unanimously observed, that sound travels at a uniform rate, viz. that it will go as far again in two seconds, as it will in one second; that it will go three times as far in three seconds, or four times as far in four seconds, as it will in one, and so on. Therefore, in the above-mentioned manner of performing the experiment, if the distance (in feet) between the cannon, and the observer, be divided by the number of seconds elapsed between the perceptions of the flash and of the report, the quotient will shew the rate of travelling, or how many feet per second sound runs through.

This rate has been estimated differently by different persons, whose experiments have been performed at different times, in different places, and with instruments more or less accurate, viz.

By

Feet  
per Second.

(a) By Sir Isaac Newton, at the rate of	968
(b) By the Hon. Mr. Robarts, at	- 1300
(c) By the Hon. Mr. Boyle, at	- - 1200
(d) By Mr. Walker, at	- - - 1338
(e) By Mersennus, at	- - - - 1474
(f) By the Florentine Academicians	- 1148
(g) By the French Academicians	- 1172
(h) De Thury, Maraldi, and de la Caille	- - . - - - - 1107
(i) By Flamstead, Halley, and Derham,	at - - - - - - - 1142

Dr. Derham, as it appears from the account in the Philosophical Transactions, seems to have made the greatest number of accurate and more diversified experiments; therefore we may take his conclusion, which coincides with those of Flamstead and Halley, as the nearest to the truth, viz. that,

- (a) Principia. B. II. Prop. 50.
- (b) Phil. Trans. n. 209.
- (c) Essay on Motion.
- (d) Phil. Trans. n. 247.
- (e) Ballistic. Prop. 39.
- (f) Exp<sup>s</sup>. of the Acad. *del Cimento*. p. 141.
- (g) Du Hamel Hist. Acad. Reg.
- (h) They reckoned it equal to 173 toises, which are nearly = 1107 feet English. See Mem. de l'Acad. for 1738, p. 128, &c.
- (i) Phil. Trans. Jones's Abrid. vol. IV. p. 396.

in general, sound travels uniformly through the atmospherical air at the rate of 1142 feet per second, or one mile in little less than 5 seconds; at least, this result cannot differ from the truth by more than 15 or 20 feet\*. But it will appear from the following paragraphs, and from the difficulty of measuring time to a fraction of a second, that no very great degree of accuracy can be expected in measurements of this sort.

Derham observed, that the report of a cannon fired at the distance of 13 miles from him, did not strike his ear with a single sound, but that it was repeated five or six times close to each other. "The two first cracks," he says, "were louder than the third, but the last cracks were louder than any of the rest. - - - - And besides, in some of my stations, besides the multiplied sound, I plainly heard a faint echo, which was reflected by my church, and the houses adjacent."

This repetition of the sound probably originated from the reflection of a single sound from hills, houses, or other objects, not much distant from the cannon. But it appears from general observation, and where no echo can be suspected, that the sound of a cannon, at the distance of 10 or 20 miles, is different from the sound when near. In

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\* According to Mr. Hales, the undulation of water is to the motion of sound as 1 to 865.

the latter case the crack is loud and instantaneous, of which we cannot appreciate the height. Whereas in the former case, viz. at a distance, it is a grave sound, which may be compared to a determinate musical sound; and, instead of being instantaneous, it begins softly, swells to its greatest loudness, and then dies away growling.—Nearly the same thing may be observed with respect to a clap of thunder. Other sounds are likewise altered in quality by the distance.

Upon the whole, it appears that the velocity of sound is exactly the same, whether the sound be high or low, strong or feeble, whether it be the sound of a human voice, or the report of a cannon. But its velocity is sensibly altered by winds. If the wind conspires with the sound, viz. if it blows in the direction from the sounding body to the hearer, the sound will be heard sooner; and if the wind blows the contrary way, the sound will be heard later, than according to the rate of 1142 feet per second. In short, the velocity of the wind, in the former case, must be added to, and in the latter it must be subtracted from, that of the sound\*. But

the

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\* The knowledge of this fact will enable us to measure pretty nearly, the velocity of the wind in certain cases; for if a cannon be fired at a known distance from us, the report must reach us sooner when the wind blows from that place to us, and later when it blows the contrary way, than it will

he velocity of the air in the strongest wind is, perhaps, not equal to the twentieth part of the velocity of sound.

Heat and cold seem to make a very small alteration in the velocity of sound; for sound appears to travel a little faster in summer than in winter.

Different altitudes of the barometer, as also different quantities of moisture in the air, seem to occasion a small alteration in the velocity of sound. But it is not in our power to determine what share of the effect is due to each of those causes.

Upon the whole it appears, that whatever increases the elasticity of the air, accelerates the motion, as also the intensity of sound, through it, and *vice versa*. Or in fluids of a determinate elasticity, whatever increases the density, diminishes the velocity of sound through them. Probably the velocities of sound through such fluids, are as the square roots of the densities.—Experience seems to prove, that at different times of the year (the influence of winds being excluded) the velocity of sound may be faster or slower, not exceeding 30 feet, than at the above-mentioned mean rate of 1142 feet per second.

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in calm weather; therefore, knowing in what time it ought to reach us in calm weather, the difference between that time and the time observed in the above-mentioned cases of windy weather, is the time which the wind employs in passing through that distance.

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The knowledge of the velocity of sound through the air, may be applied to a very useful purpose, viz. to the measurement of distances, especially when no better method can be used with convenience. Thus we may measure the distance of a thunder cloud by measuring the time which elapses between the appearance of the flash of lightning, and the report of the explosion or thunder; for if by looking upon a clock or a watch with a second's hand, we find that the time elapsed is one second, we may conclude that the explosion took place at the distance of 1142 feet from us; if the elapsed time be two, or three, or any other number of seconds, we may conclude that the distance is the product of 1142 multiplied by two, or by three, or by the other number of seconds. After the same manner by observing the flash and the report of a gun, or the motion of the hand which moves an hammer, and the perception of the sound, &c. we may determine, pretty nearly, the distance of a ship, or of an island, or of a workman, &c.

Air is always around us, and therefore is the most common medium through which sounds are transmitted: but sounds may also be conveyed by other bodies, both solid and fluid, viz. by water, by metals, by wood, by stones, by ropes, &c. and in most cases more readily and perfectly than by the air. Probably there is no substance which is not in some measure a conductor of sound; but sound is much enfeebled by passing from one medium to another.

If a man stops one of his ears with his finger, stops the other ear by pressing it against the end of a long stick, and a watch be applied to the opposite end of the stick, or of a piece of timber, be it ever so long, the man will hear the beating of the watch very distinctly; whereas in the usual way through the air, he can hardly hear it from a greater distance than about 15 feet.

The same effect will take place if he stops both his ears with his hands, and rests his teeth, his temple, or the cartilaginous part of one of his ears against the end of the stick.—Instead of a stick he may use a rod of iron or other metal, a block or pillar of marble, &c.

Instead of applying the watch, a very gentle ratch may be made at one end of a pole, or rod, and the person who keeps the ear in close contact with the other end of the pole, after the above-mentioned manner, will hear it with great accuracy.

Thus persons who are not quick of hearing, by applying their teeth to some part of an harpsichord, or other sounding body, will, by that means, be enabled to hear the sound much better than otherwise.

If a man stops his ears with his hands, then passes a loop of a string (which has a piece of metal, as spoon, &c. tied to its extremity) over his head and hands, and by stooping himself a little, keeps the end of the string, with the spoon or piece of metal, pendant before him; on striking the spoon against

against any thing, he will hear a sound not much different from that of a large bell.—Such experiments are capable of great variety\*.

It has been said, that the report of cannons fired at Toulon may be heard at Monaco, viz. at the distance of about 76 miles, by a person lying on the ground; but not otherwise. But the practice of placing one's ear close to the ground, in order to perceive the approach of horses or men; or, in short, for the purpose of hearing distant sounds, has been observed even amongst uncivilized nations.

Articulate sounds may also be transmitted through solids; but I must own, they are not perceived very distinctly by my ear. However, Dr. Chladni, who has made a vast number of experiments relative to this subject, expresses himself in the following manner :

“ Articulated tones also are conducted exceedingly well through hard bodies, as I found by experiments which I made with some of my friends. Two persons who had stopped their ears, could converse with each other when they held a long stick, or a series of sticks, between their teeth, or rested their teeth against them. It is all the same whether the person who speaks rests the stick against his throat or

\* See the Mem. of the Ac. of Turin, for 1790 and 1791.

" his breast, or when one rests the stick which he  
" holds in his teeth against some vessel into which  
" the other speaks. The effect will be greater  
" the more the vessel is capable of a tremulous  
" movement. It appeared to be strongest with  
" glass and porcelain vessels; with copper kettles,  
" wooden boxes, and earthen pots, it was weaker.  
" Sticks of glass, and next fir-wood, conducted the  
" sound best. The sound could also be heard  
" when a thread was held between the teeth by  
" both, so as to be somewhat stretched. Through  
" each substance, the sound was modified in a  
" manner a little different. By resting a stick or  
" other body against the temples, the forehead, and  
" the external cartilaginous part of the ear, sound  
" is conveyed to the interior organs of hearing, as  
" will readily appear if you hold your watch to  
" those parts of another person who has stopped up  
" his ears. From this it appears, as well as from  
" the experiments relative to the hearing under  
" water, that hearing is nothing else than, by  
" means of the organs of hearing, to be sensible  
" of the tremulous movement of an elastic body,  
" whether this tremulous movement be conveyed  
" through the air, or any other fluid or hard body,  
" to the auricular nerves. It is also essentially the  
" same whether, as is usually the case, the sound  
" be conveyed through the internal part of the  
" ear, or whether it be communicated through  
" any other part of the body. It certainly would

" be worth the trouble to make experiments to try whether it might not be possible that deaf and dumb people, when the deficiency lies only in the external organs of the ear, the auricular nerve being perfect, could not, by the above method of conducting sound, be made to hear, distinctly, words articulated, as well as other sounds?"

The velocity with which sound moves through solids, is by no means known, nor does it seem likely to be determined experimentally; for such experiments can only be performed with several hundred feet length of each particular substance. The only thing which has been tried relative to this subject, is to transmit a sound through a series of pieces of wood placed in close contact the first with the second, the second with the third, and so on. It was found that sound is transmitted through wood faster than through air; but it could not be determined how much faster †.

### Whether

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\* This has been taken from the Phil. Mag. for July 1799, which contains the translation of some passages extracted from Dr. Chladni's original work on the longitudinal vibrations of strings, &c.

† By reasoning and calculation it has been deduced, that a column of air in a pipe of a certain length, open at both ends, makes one longitudinal vibration in the same time that sound would employ to percur the same length of air;

Whether sound be transmitted at all through vacuum, or not, is by no means determined. A bell inclosed in a glass receiver, and caused to sound, can be heard less and less, according as the glass is more and more exhausted of air; but though I have used one of the best air-pumps that was ever constructed, and the apparatus which supported the bell was laid upon such soft substances as seemed least likely to transmit the sound through them; yet I could never render the sound of the bell quite un-audible. Besides, it may be suspected, that when the glass receiver is exhausted of air, the pressure of the atmosphere, on its outside only, may check in great measure the transmission of the sound. If it be asked what can transmit the sound, or the vibrations of the bell, when the air between it and the glass has been removéd, supposing that it might be entirely removed? We must undoubtedly assert our ignorance of it. But our ignorance of what may transmit the sound in that case, does not prove that

air; (*Riccati delle fibre elastiche.* Newton's Princip. L. 2. Prop. 50.) hence it may be presumed, by analogy, that sound is transmitted by solids of a certain length in the same time in which those solids would perform each of their longitudinal vibrations. Now it has been found that a rod of iron of a certain length, will perform its longitudinal vibrations much faster than an equal pillar of air; therefore it is likely that sound will move through iron much faster than through air, and the same thing may be said of other solids.

the sound could not be heard if the air were entirely removed.

Sounds diminish in intensity, or they are less audible, according as the hearers are farther from the sounding body; but there is no accurate method of determining this decrease\*.

The same sound is stronger in dense than in thinner air. The actual fall of rain, snow, &c. or a good deal of moisture in the air, diminish the intensity of sound. In calm, serene weather, when every thing is quiet, a sound is heard much stronger, and of course much farther than otherwise. When a smooth surface of ground, and especially of water, is interposed between the sounding body and the hearer, then sounds may be heard much farther than when water much agitated, or ground covered with houses, trees, &c. is interposed.

In favourable circumstances the striking of the clock on the bell of St. Paul's church, in London, has been heard at Windsor. It has been said that with a particular concurrence of favourable circumstances, the human voice has been heard at the distance of more than ten miles, viz. from Old Gibraltar to New Gibraltar†. The discharge of an ordinary musket can hardly ever be heard farther

\* See the Phil. Trans. for 1800, p. 120.

† Derham's Physico-Theology, B. IV. chap. 3. See also the Phil. Trans. N. 300, for more facts of this nature.

n seven or eight miles; but the discharge of several such muskets at the same time may be heard in a greater distance. The quick repetition of the same sound may also be heard somewhat farther in the same singly. In the Dutch war of the year 1672, it has been said, that the reports of can-  
is were heard at the distance of 200 miles, and upwards.

It is commonly said, that the vibrations, which are communicated to the air by a sounding body, extend spherically all round that body; and in fact the sound may be heard on any side of it; yet certain it is, that the sound will not be heard with equal force and distinction in every direction; and this difference is much greater with certain sounding bodies, (viz. when a strong impulse is given to the air in a particular direction) than with others. The report of a cannon appears louder to a person towards whom it is fired, than to one situated in a contrary direction\*. The speaking trumpet throws the sound directly before its aperture, and very little of it can be heard by persons who are out of that direction†. In windy weather

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\* Phil. Transl. for 1800, p. 118.

† Upon this principle several curious contrivances may be made; and the speaking of the inanimate figure, suspended in the air, which was exhibited in London some

the sound of a distant bell is perceived to increase or decrease in loudness, according as the wind alters

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years ago, depends upon the same principle. The mechanism was as follows: A wooden figure was suspended in the air by means of ribbands, in an opening between two rooms. There was a perforation about an inch and a half in diameter, from the mouth to the upper part of the head. This aperture had an enlarged termination on the top of the head, and with the other extremity communicated with a sort of speaking-trumpet, which was fastened to the mouth of the figure. Behind the partition the enlarged or funnel-like opening of a tube was situated directly opposite to, and at about two feet distance of, the aperture on the head of the figure. The tube behind the partition was bent in a convenient form, and a concealed performer applied either his mouth or his ear to the other end of the tube. Now, if a person applied his mouth to the opening of the trumpet, and spoke into it, the sound passed from the opening on the head of the figure through the air, to the opening of the tube which stood facing it behind the partition of the rooms, and the person, who applied his ear to the farther opening of the tube, would hear it distinctly; but other persons in the room heard very little, if at all, of the said articulated sound; and the same thing took place, when the concealed person spoke with his mouth close to the farthest end of the tube, and another person placed his ear close to the opening of the trumpet; which shews that the sound passed almost entirely in a straight direction, from the opening on the head, to the opposite aperture of the tube, and *vice versa*. This made it appear as if the wooden figure itself comprehended words, and returned an adequate answer.

its strength or its direction. An obstruction to the direction of sounds, is evidently made by hills, houses, large trees, and other bodies of a certain extent ; for the sound of a distant bell, of a mill, of the waves of the sea on the shore, &c. may be heard much better when nothing solid is interposed between the hearer and the sounding body, than otherwise. This may be easily observed by a person walking through a town, when a noise proceeds from any of the above-mentioned causes ; for he will hear the noise much better when he comes to the opening of a street which leads to the sounding place, than when the houses intervene ; so that the sound which comes out of an aperture, does not expand spherically round that aperture, as round a centre ; and this is analogous to what has been said with respect to the direction of a stream of water, which comes out of an aperture (see p. 178.) ; but it must be confessed, that we are less able to comprehend the real motion of the air, than that of the waves on the surface of water, or that of a stream.

Sounds are also reflected by hard bodies, and this reflection produces the well-known phenomenon, called the *echo* ; and others analogous to it.

If a person standing at a certain distance before a high wall, a bank, a rock, &c. utters a word or makes a noise, either with his voice or with an hammer, &c. he will frequently hear a repetition of the word or other noise ; and the time which

clapses between the expression of the sound and the hearing of the same again, is the same as would be found in general in going twice through the distance between the man and the wall, or the rock, &c. for the vibrations of the air must go from the man to the wall, and back again; so that if the wall be 1142 feet distant, the time elapsed between the expression of the sound, and the second arrival of it to the ear, will be two seconds; and so forth.

But the same original sound, and the repetition of it, which is called the *echo*, may be heard by other persons situated at different distances both from the original sounding place, and from the reflecting wall, or other object. The effect, however, will not be exactly alike; for instance, those who are nearer to the wall, will hear the echo sooner than other persons; those who are as far again from the man who expresses the sound as they are from the reflecting obstacle, when the reflecting object is at an equal distance from both, will hear both the original sound and the echo at the same time; in which case they will perceive, as it were, one sound louder than they would without the repetition.

But though several persons in different situations will hear the echo or repetition of the same sound; yet in a particular direction, the echo may be heard much better than in other directions. Now, if two straight lines be drawn from the centre or middle of

the reflecting surface, one to the place whence the original sound proceeds, and another in the above-mentioned best direction; those lines will be found to make equal angles with, or to be equally inclined to, that surface. Hence it is said, *that sound is reflected by certain bodies, and that the angle of reflection is equal to the angle of incidence.*

This shews, that though sound proceeds from an original sounding body, or from a reflecting surface, in every direction; yet a greater quantity of it proceeds in some particular direction than in any other; and this is probably owing to the original impulse being given to the air in one direction more forcibly than in others, as also to the want of perfect freedom of motion in the aërial fluid.

The surface of various bodies, solids as well as fluids, have been found capable of reflecting sounds, viz. the sides of hills, houses, rocks, banks of earth, the large trunks of trees, the surface of water, especially at the bottom of a well, and sometimes even the clouds. It is therefore evident, that in an extensive plain, or at sea, where there is no elevated body capable of reflecting sounds, no echo can be heard.

The configuration of the surface of those bodies seems to be much more concerned in the production of the echo, than the substance itself. A smooth surface reflects sounds much better than a rough one. A convex surface is a very bad reflector of sound; a flat surface reflects it very well;

but a small degree of concavity, and especially when the sounding body is in the centre, or focus, of the concavity, renders that surface a much better reflector.

Thus in an elliptical chamber, if the sounding body be placed in a focus of the ellipsis, that sound will be heard much louder by a person situated in the other focus, than in any other part of the chamber. In this case the effect is so powerful, that even when the middle part of the chamber is wanting, viz. when the two opposite elliptical shells only exist, the sound expressed in one focus will be heard by a person situated in the other focus, but hardly at all by other persons\*.

This in some measure explains the effect of what are called *whispering domes*; and *whispering galleries*; wherein, if a person speaks pretty near the wall on one side of it, another person will hear him distinctly when he places his ear pretty near the wall on the opposite side. The dome in St. Paul's cathedral, in London, has this curious property,

\* If from any point in the circumference of an ellipsis, two lines be drawn to the foci, those lines make equal angles with the curve at that point. This is demonstrated by all the writers on conics. Therefore, the sound which is produced in one focus of an elliptical chamber, and is reflected from the wall to the other focus, makes all the angles of incidence equal to the angles of reflection respectively. Hence, that focus is the place where the sound is heard best.

which

which is generally shewn to all enquiring visitors.

Several phenomena may be explained so easily upon the above-mentioned theory of the reflection of sound, that they need be merely mentioned to the intelligent reader.

Several reflecting surfaces frequently are so properly situated with respect to distance, and directions, that a sound proceeding from a certain point, is reflected by one surface first, then by another which is a little farther off, after which it is reflected by a third surface, and so on; or it is reflected from one surface to a second, from the second to a third, from the third to a fourth, &c. Hence, echos, which repeat the same sound, or the same word, two or three, or several times over, are frequently met with.

According to the greater or less distance from the speaker, a reflecting object will return the echo of several, or of fewer syllables; for all the syllables must be uttered before the echo of the first syllable reaches the ear, otherwise it will make a confusion. In a moderate way of speaking, about  $3\frac{1}{2}$  syllables are pronounced in one second, or seven syllables in two seconds\*. Therefore, when an echo repeats

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\* From the computation of short-hand writers it appears that a ready and rapid orator in the English language, pronounces from 7000 to 7500 words in an hour, viz. about 120 words in a minute, or two words in each second. Memoirs of Gibbon's Life.

seven syllables, the reflecting object is 1142 feet distant; for sound travels at the rate of 1142 feet per second, and the distance from the speaker to the reflecting object, and again from the latter to the former, is twice 1142 feet. When the echo returns 14 syllables, the reflecting object must be 2282 feet distant, and so on. A famous echo is said to be in Woodstock Park, near Oxford. It repeats 17 syllables in the day, and 20 at night\*. Another remarkable echo is said to be on the north side of Shipley church, in Sussex. It repeats distinctly, in favourable circumstances, 21 syllables †.

I therefore find the farther the reflecting surface is, the greater number of syllables the echo will repeat; but the sound will be enfeebled nearly in the same proportion, and at last the syllables cannot be heard distinctly.

When the reflecting object is too near, the repetition of the sound arrives at the ear, whilst the perception of the original sound still continues, in which case an indistinct resounding is heard. This effect may be frequently observed in empty rooms, passages, &c. especially because in such places several reflections from the walls to the hearer, as also from one wall to the other, and then to the

\* Dr. Plot's Nat. Hist. of Oxfordshire.

† Harris's Lex. Tech. Article ECHO.

hearer,

bearer, clash with each other, and increase the indistinction.

If each of the vibrations of the air, which are occasioned by a certain sound, be performed in the same time that sound employs in going from the sounding body to the walls of a room, and thence to the hearer, then the sound will be heard with greater force. In short, by altering our situation in a room and expressing a sound, or hearing the sound of another person, in different situations, or when different objects are alternately placed in the room, that sound may be heard louder or weaker, and more or less distinct. Hence it is, that blind persons, who are under the necessity of paying great attention to the perceptions of their sense of hearing, acquire the habit of distinguishing, from the sound even of their own voices, whether a room is empty or furnished, whether the windows are open or shut, and sometimes they can even distinguish whether any person be in the room or not\*.

A great

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\* The famous Dr. N. Saunderson, Professor of the Mathematics in the university of Cambridge, who had been blind since he was one year old, possessed such acuteness of hearing, that, as is related in the account of his life, " By his quickness in this sense, he not only distinguished persons, with whom he had ever once conversed, so long as to fix in his memory the sound of their voice, but in some measure places also. He could judge of the size of a room

A great deal of furniture in a room, especially of a soft kind, such as curtains, carpets, &c. check in great measure the sounds that are produced in it; for they hinder the free communication of the vibrations of the air, from one part of the room to the other.

The fittest rooms for declamation, or for music, are such as contain few ornaments that obstruct the sound, and at the same time have the least echo possible; for when they have one or more echos, which arise from cupolas, alcoves, vaulted ceilings, &c. the repetition of one or more sounds comes to the ear at the same time that another direct sound reaches it, which not only spoils the singer, but nine times out of ten forms a discord.

A pretty strong and continued sound fatigues the ear. The strokes of heavy hammers, of artillery, &c. are apt to render people deaf, at least for a certain time. And it has been observed, that some persons who have been long exposed to the continued and confused noise of certain manufactures, or of water-falls, or of other noisy places, can

" into which he was introduced, of the distance he was  
 " from the wall: and if ever he had walked over a pavement in courts, piazzas, &c which reflected a sound, and  
 " was afterwards conducted thither . . . . , he could exactly  
 " tell whereabout in the walk he was placed, merely by the  
 " note it sounded."

what

what is spoken to them, much better in the midst of that noise than elsewhere.

The attentive reader may naturally enquire in what manner are sounds communicated to our sensuum, and in what manner does the ear receive and transmit them to the auditory nerve; but to these questions I am unable to give any satisfactory answer. A particular description of the internal, as well as external, parts of the ear, may be found in a variety of anatomical books; but the knowledge of the construction does not inform us of the real use of those parts. The form of the external part of the ear is evidently intended for receiving in great quantity, and for concentrating the vibrations of the air.

Some very remarkable observations lately made, relative to the organ of hearing, shew, in a very pointed manner, that the various functions of that organ are far from being rightly understood\*. A proper investigation of the subject is highly commendable to every able philosopher.—It might doubtless improve the general subject of acoustics, and in particular it might furnish means of remedying, or of supplying, the defects incident to the human ear.

The only known mechanical method of improving that organ, when it is in a certain manner defective, is by the use of the *bearing trumpet*.

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\* See Mr. Astley Cooper's Paper, in the Phil. Trans. for 1800, page 151.

This trumpet is an hollow conical tube, from about 8 to 16 inches in length. It is often bent not much unlike the letter C, excepting that in general the small end is bent much less than the other. The small end (whose aperture is not above a quarter of an inch in diameter) is applied to the ear, whilst the large aperture (which is from about 2 to 4 inches in diameter) is directed towards a speaker, or towards the sounding body. By this means the sound is heard considerably louder, but less distinct.

Hearing trumpets have been made of various shapes, though the above seems upon the whole to be the best ; but no theory can at present determine their most advantageous construction.

Their office is to increase, not the frequency, but the momentum of the aerial vibrations; and this may probably arise from those vibrations passing gradually from the larger to the narrower part of the instrument. Perhaps the vibrations of the air reflected from different points of the instrument, like different echos, reach the ear not all precisely at the same time ; hence the sound is rendered louder, but less distinct. I shall not however proceed to explain what I myself do not clearly understand.

## CHAPTER XII.

## OF MUSICAL SOUNDS.

**A** Succession of sounds has been called *Melody*.

The compound effect which arises from two sounds, expressed at the same time, is called *Consonance*, or *Dissonance*, according as it produces a pleasing or unpleasing effect.

An *Accord* is the effect which arises from, or a combination of, more than two sounds expressed at the same time.

A succession of accords is called *Harmony*.

The art which examines, disposes, and expresses sounds, so as to produce melody, or harmony, pleasing upon the whole, is called *Music*, or the *Musical Art*. And the sounds, which are so far simple, determinate, and pleasing, as to be used in music, are called *Musical Sounds*.

It has been said, at the beginning of the preceding chapter, that the variety of sounds arises from three causes principally, viz. 1st, from the greater or less frequency of the vibrations ; 2dly, from the quantity, force or momentum of the vibrating parts ; and 3dly, from the greater or less simplicity of each sound.

A clear idea of those differences may be conceived by comparing the sound of a pretty large bell, with that of a string of a base viol. Those two sonorous bodies may be adjusted so, that each of them may perform the same number of vibrations in the same time. In that case the sounds of those instruments are said to be of the same *pitch*; for the pitch of a certain sound, or of the instrument which expresses that certain sound, is said to be equal to, lower, or higher than the pitch of another sound, or other sonorous body that emits that sound, when the first sonorous body performs an equal, a smaller, or a greater number of vibrations than the other sonorous body in the same time.

But though those instruments express the same sound with respect to the pitch; yet the sound of the bell is much louder than that of the base viol; and, in fact, the former may be heard from a much greater distance than the latter. This shews the second distinction \*

\* The greater or less strength of a sound of the same pitch is called by musicians, the *forte* and *piano* of that sound. The well known instrument, called the *forte piano*, derives its name from its being capable of expressing the same tones more or less loud; whereas the harpsichord, which is like the forte piano in every other respect, expresses its tones always of the same strength.

The third arises from the inequality, harshness, &c. of the sound of the bell in comparison with that of the base viol; for a person, who is sufficiently near, and listens with attention, will perceive that the sound of the bell is attended with a sort of undulation, both in pitch and strength; and is, besides, accompanied with one or more secondary sounds; whereas the sound of the base viol is much more simple and uniform.

There is no method of measuring the quantity of the above-mentioned second and third distinctions; excepting by the judgment of the ear, which is various and partial. One person, for instance, prefers the sound of a powerful organ to that of a violin; another prefers the latter to the former. One likes the sound of a French horn above that of all other instruments, and another prefers a flute.

In general it is not from a proper discrimination, but from the various acuteness of the ear, from prejudice, from fashion, from want of discernment, or from mistaken ideas, that most people express their likings and dislikings. Various and discordant are the opinions of men relatively to those things which have no fixed standard of perfection or demonstration; yet it may be presumed, especially with respect to musical sounds, that whatever pleases the majority, and whatever can be endured for a longer time without disgust, is the best and the most eligible. And there are some persons

who, from knowledge, practice, sensibility, and a proper use of their reasoning faculty, have enabled themselves to discriminate at once between what is, and what is not, more likely to please the majority, or to be endured longer without disgust.

After a long and diversified experience, through a considerable series of years, it has been found, that certain sounds, expressed in certain successions, and in certain combinations, are pleasing to most human ears. They are of the simplest and most uniform kind, neither too loud, nor too feeble; but differing from each other in pitch, by certain fixed and determinate intervals.—They are called *musical sounds, or tones.*

Besides the human voice, several instruments, which have been invented at various times, and are now in use, are capable of expressing those musical sounds; hence they are called *musical instruments*, and the best of them are such as are capable of expressing the greatest variety of such sounds, especially with respect to the pitch, and of the simplest, as well as of the most pleasing sort.

Upon some of those instruments, such as the harpsichord, forte piano, the organ, the guitar, &c. the pitch of each tone is fixt and immutable. In others, such as the human voice, French horn, violin, violoncello, &c. the pitch proper for each tone, must be determined by the performer. The accomplishment of this task is very difficult, and

from

from this are the musical performers said to have a good or a bad intonation.

What has been said above may suffice with respect to the less definite qualities of sounds; viz. strength and simplicity. It is now necessary to treat of the more difficult, but more determinate, quality, called the *pitch*, which has already been said to depend upon the frequency of the vibrations.

The human voice, in its ordinary way of speaking, generally changes its pitch by imperceptible intervals, or rather by sliding a little way up or down. But there are different and considerable intervals between the musical tones. Those musical tones were perhaps in great measure found out experimentally; but they have afterwards been reduced to, and may be expressed by means of, accurate mathematical measurements.—The order, or the arrangement, of those sounds is called *the scale of music*.

A voice or an instrument, which expresses those sounds in a particular order under certain restrictions, produces music; otherwise the effect is not pleasing, nor is it called music. The natural singing of birds may exhibit a fine voice in certain cases; but it is not musical, their sounds having nothing to do with the musical intervals; and, in fact, the arrangement of their various sounds is by no means pleasing.

The number of vibrations which may be performed

formed by a stretched string, when its tension, length, and weight are known, may be ascertained with tolerable accuracy.

The number of vibrations of most other sounding bodies, cannot be ascertained otherwise than by comparing their sounds with those of stringed instruments; for the human ear can judge with considerable accuracy when the two instruments are in unison, or perform contemporaneous vibrations, in which case they are said to be *of the same pitch*; and indeed some expert musicians can determine by the judgment of their ear, not only when two sounds are of the same pitch, but also when they are at a certain distance of each other. Therefore, in our investigation and expressions of musical sounds, it will be sufficient to speak of stretched strings or chords only; as the sounds of all the other instruments may be referred to those of strings.

The following particulars relative to stretched strings have been demonstrated mathematically, and the demonstration will be found in the following note, for the use of those readers who are sufficiently skilled in mathematics.

i. If a stretched cylindrical chord be struck, and then be left to vibrate by itself, it will perform its vibrations, whether large or narrow, in equal times, and, of course, the sound, though decaying gradually, yet continues in the same pitch; excepting, however, when the string is struck violently; for in that case its sound is a little higher at first,

viz. its vibrations are a little more frequent at first.

2. If various strings be equally stretched, and be of the same substance; or, in short, if they be equal in every respect, excepting in their lengths; then the duration of a single vibration of each string will be as the length of the string; or (which is the same thing) the number of vibrations performed by each string in a given time, will be inversely as the length; for instance, if a string be four feet long, and another string, *ceteris paribus*, be one foot long; then the latter will vibrate four times whilst the former vibrates once. Or if the length of the former be to that of the latter, as 10 to 3; then the vibrations performed by the latter will be to those that are performed by the former, as 3 to 10; and so on. Also, the same thing must be understood of the parts of the same string; for instance, if a certain string perform 8 vibrations in a second; then, if that string be stopped in the middle, and one half of it only be caused to sound, then that half will perform 16 vibrations in a second.—One third part of the same string will perform 24 vibrations in a second; and so on.

The length of the string is reckoned from one bridge to the other, or from one resting place to the other; thus, in fig. 19. Plate XIII. the length of the string is reckoned from R to S. The tension of the string is measured by the

weight  $w$ , which is suspended to one end of it. If instead of stretching a string by suspending a weight to it, as indicated by the above-mentioned figure, the string be twisted round a peg, after the manner commonly used in musical instruments, then the tension still must be expressed by a weight; meaning a weight which may be capable of stretching the string as much as it is stretched by turning the peg.

3. If various chords differ in tension only; then the number of vibrations which each of them performs in a given time, is as the square root of the stretching weight. Thus, if a chord be stretched by a weight of 16 pounds, and another chord be stretched by a weight of 9 pounds; then the former will perform 4 vibrations in the same time that the latter performs 3 vibrations.

4. If cylindrical chords differ in thickness only; then the number of vibrations which they perform will be inversely as the diameters, viz. if the diameter of a chord be equal to twice the diameter of another chord; then the former will perform one vibration in the same time that the latter performs two vibrations.

5. By a proper adjustment of the lengths, thicknesses, and stretching weights, dissimilar chords may be caused to perform any required number of vibrations; which is evidently derived from the preceding paragraphs.

6. The actual number of vibrations, which are performed by a given stretched chord, may be determined, without any great error, by using the following rule; provided the length and weight of the vibrating part of the chord, as RS, fig. 19, and likewise the stretching weight  $w$ , be known.—  
*Rule.* Multiply the stretching weight by 39,12 inches (which is nearly the length of the pendulum that vibrates seconds). Also multiply the weight of the chord by its length in inches; divide the first product by the second; extract the square root of the quotient; multiply this square root by 3,1416, and this last product is the number of vibrations that are performed in one second of time by the given chord.—The resistance of the air, as also some other fluctuating causes of obstruction, not being noticed in this rule; it is most probable that the real vibrations are not quite so numerous as they are given by the rule.

*An example of the above-mentioned rule.*—A copper wire of 35,55 inches in length, weighing 31 grains troy, was stretched by a weight of seven pounds avoirdupois, which is nearly equal to 49000 grains. How many vibrations did it perform in each second? — The product of 49000 multiplied by 39,12 is 1916880. The product of 35,55 by 31, is 1102,05. If 1916880 be divided by 1102,05, the quotient will be 1739,37, the square root of which is 41,7; and

and this square root being multiplied by 3,1416, gives 131 for the required number of vibrations. (1.)

It

(1.) It is evident from what has been said above, that by diminishing the tension and increasing the length of the chord, the number of vibrations may be diminished to such a degree as to render the single vibrations discernible from each other; hence it seems, that the vibrations of a chord that expresses a certain tone, might be counted; but in practice the performance of such experiments is attended with very great, and hitherto unsurmounted, difficulties. Several persons have tried the experiment; but no decisive results have ever been derived therefrom.

I have attempted such experiments, both with metallic and with catgut strings of various sizes and lengths, as far as 17 feet; and with various degrees of tension, or with various stretching weights. I have used those strings in the manner of pendulums, with a weight fastened to the lower extremity;—I have also placed them horizontally, after the above-mentioned manner of fig. 19. Plate XIII; but the effect was, that when the vibrations were fewer than ten or twelve in a second, which is the greatest number I can possibly count with tolerable certainty; then the sound of the chord was so very indistinct, equivocal, and encumbered with other sounds, that I could not be certain of its pitch. If by increasing the weight, or by shortening the chord, the tone was rendered sufficiently distinct; then the vibrations were thereby quickened beyond the possibility of counting them.

Nevertheless, I shall subjoin the particulars of one of those experiments, which was repeated several times, both by

It is now necessary to specify those sounds which experience has shewn to be fit for musical composition. And here we shall only speak of the pitch, which is denoted by the number of vibrations that are

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by myself, and in the presence of a very intelligent friend; hence it may be presumed to be as accurate as the nature of the subject can admit of.

A brass string, such as is used for harpsichords, was suspended like a pendulum, with a weight of  $5\frac{1}{2}$  pounds, (viz. 40250 grains) at its extremity.

The length of the string was 100 inches. Its weight 130 grains; when struck and set a vibrating, if a piece of paper was set on one side of it, the string struck the paper about 14 times in a second, as nearly as I could possibly reckon. And as it would have struck a piece of paper on the other side as often in the same time, therefore it performed 28 vibrations in a second.

But, by calculation, it ought to have performed 34,56 vibrations in a second.

When, instead of 5 pounds and  $\frac{1}{2}$ , one pound only, or 7000 grains, was suspended to it, the string performed from 10 to 12 vibrations in a second; and in fact the numbers of vibrations being as the squares of the stretching weights, we have  $40250\frac{1}{2} : 7000\frac{1}{2} :: 200,6 : 83,6 :: 28 : 11,6$ ; which is a pretty good agreement.

By calculation it ought to have performed 14,3 vibrations in a second.

Therefore, it seems, that the method of determining the number of vibrations that are performed by a string which sounds a certain tone, must be derived from the theoretical demonstration; but the result of such demonstration must deviate

are performed in a given time, or by the length of the string which emits each of those sounds ; for it has been already shewn that, when stretched strings are alike in all other respects, excepting in their lengths,

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deviate in a certain degree from the truth, principally on account of the resistance of the air, and of the want of perfect pliability in the chord, &c.

The ratio which the number of vibrations bears to the weight, tension, length, &c. of the chord, has been demonstrated, with some variation of method, by several able writers. The conclusion is always the same. I have, however, preferred Dr. Taylor's original demonstration, such as is published in the Philosophical Transactions, because it is less dependent upon other extraneous propositions, and of course it may be esteemed the most concise.

It may be objected, that this démonstration does not take in all the shapes which a string, according to the various modes of striking it, assumes in its vibrations. But it must be observed, that as, *cæteris paribus*, the same chord, however struck, provided it be not struck too violently, gives a tone constantly of the same pitch ; its vibrations must be as frequent when it assumes the simplest, as when it assumes any other, form.

*Of the Motion of a Stretched String, by Dr. B. Taylor.*

*Pbil. Trans. N. 337. or Jones's Abridg. vol. IV. p. 391.*

\* Lemma 1. Let A D F B, A Δ Φ B, fig. 1. Plate XIV. be two curves, the relation of which is such, that the ordinates

lengths, then the duration of a single vibration of each string, is proportionate to the length of the string; or, (which amounts to the same thing) that the number of vibrations performed by each string

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ordinates  $C\Delta D$ ,  $E\Phi F$ , being drawn, it may be  $C\Delta : CD :: E\Phi : EF$ . Then the ordinates being diminished *ad infinitum*, so that the curves may coincide with the axis  $AB$ ; I say, that the ultimate ratio of the curvature in  $\Delta$ , will be to the curvature in  $D$ , as  $C\Delta$  to  $CD$ ."

"*Demons<sup>t</sup>*. Draw the ordinate  $c\delta d$  very near to  $CD$ , and at  $D$  and  $\Delta$  draw the tangents  $Dt$  and  $\Delta\theta$ , meeting the ordinate  $c\delta d$  in  $t$  and  $\theta$ . Then because of  $c\delta : cd :: C\Delta : CD$ , (by hypothesis) the tangents being produced will meet one another, and the axis in the same point  $P$ . Whence, because of similar triangles  $CDP$  and  $ctP$ ,  $C\Delta P$  and  $c\theta P$ , it will be  $c\theta : ct :: C\Delta : CD :: c\delta : cd$  (by hypoth.)  $:: \delta\theta : (c\theta - c\delta) : dt (ct - cd)$  But the curvatures in  $\Delta$  and  $D$ , are as the angles of contact.  $\theta\Delta\delta$  and  $td\delta$ ; and because  $\delta\Delta$  and  $dD$  coinciding with  $cC$ , those angles are as their subtenses  $\delta\theta$ ,  $dt$ ; that is, by the proportion above, as  $C\Delta$ ,  $CD$ . Therefore, &c. Q. E. D."

"*Lemma 2.* In some instant of its vibration, let a string, stretched between the points  $A$  and  $B$ , fig. 2. Plate XIV. put on the form of any curve  $Ap\pi B$ ; I say, that the increment of the velocity of any point  $o$ , or the acceleration arising from the force of the tension of the string, is as the curvature of the string in the same point."

"*Demons<sup>t</sup>*. Conceive the string to consist of equal rigid particles, which are infinitely little, as  $p o$ ,  $o\pi$ , &c. and at

string in a given time, is inversely as the length of the string.

If you take several strings precisely of the same substance, the same form, and the same thickness, and

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the point  $o$  erect a perpendicular  $oR$ , equal to the radius of the curvature at  $o$ , which let the tangents  $pt$ ,  $\pi t$ , meet in  $t$ , the parallels to them  $\pi s$ ,  $ps$ , in  $s$ , the chord  $p\pi$  in  $c$ . Then by the principles of mechanics, the absolute force by which the two particles  $po$  and  $o\pi$ , are urged towards  $R$ , will be to the force of tension of the string, as  $st$  to  $tp$ ; and half this force by which one particle  $po$  is urged, will be to the tension of the string, as  $ct$  to  $tp$ ; that is, (because of similar triangles  $ctp$ ,  $tpR$ ) as  $tp$  or  $op$  to  $Rt$ , or  $oR$ . Wherefore, because of the force of tension being given, the absolute accelerating force will be as  $\frac{tp}{oR}$ .

But the acceleration generated is in a compound ratio of the ratios of the absolute force directly, and of the matter to be moved inversely; and the matter to be moved is the particle itself  $op$ . Wherefore the acceleration is as  $\frac{I}{oR}$ ; that is, as the curvature in  $o$ . For the curvature is reciprocally as the radius of curvature in that point. Q. E. D."

"*Prob. I.* To determine the motion of a stretched string."

"In this and the following problem, I suppose the string to move from the axis of motion through an indefinitely little space; that the increment of tension from the increase of the length, also the obliquity of the radii of curvature, may safely be neglected."

"Therefore

and stretch them equally by suspending equal weights to their extremities, or otherwise ; then make their lengths of the proportions that are stated in the following table ; those strings, when struck, will express

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“ Therefore let the string be stretched between the points A and B, fig. 3. Plate XIV. and with a bow let the point  $\alpha$  be drawn to the distance C  $z$ , from the axis A B. Then taking away the bow, because of the flexure in the point C alone, that will first begin to move (by Lem. 2.) But no sooner will the string be bent in the nearest points  $\phi$  and  $\alpha$ , but these points also will begin to move ; and then E and  $\epsilon$  ; and so on. Also because of the great flexure in C, that point will first move very swiftly, and thence the curvature being increased in the next points D, E, &c. they will immediately be accelerated more swiftly ; and at the same time the curvature in C being diminished, that point in its turn will be accelerated more slowly. And in general, those points which are slower than they should be, being accelerated more, and the quicker less, it will be brought about at last, that the forces being duly attempered one with another, all the motions will conspire together, and all the points will at the same time approach to the axis, going and returning alternately, *ad infinitum.*”

“ Now that this may be done, the string must always put on the form of the curve A C D E B, the curvature of which, in any point E, is as the distance of the same E  $n$  from the axis ; the velocities of the points C, D, E, &c. being also in the ratio of the distances from the axis C  $z$ , D  $\beta$ , E  $\epsilon$ , &c. For in this case the spaces C  $z$ , D  $\beta$ , E  $\epsilon$ , &c. described in the same infinitely little time, will be as the velocities ; that is, as the spaces described C  $z$ , D  $\beta$ , &c.

Wherefore

express the proper musical sounds or tones, and the whole set is called the *scale of music*.

The successive expression of those musical sounds in any order, produces *musical melody*, which may be good

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Wherefore the remaining spaces  $\alpha z$ ,  $\delta g$ ,  $\epsilon u$ , &c. will be to each other in the same ratio. Also (by *Lem. 2.*) the accelerations will be to one another in the same ratio. By which means the ratio of the velocities always continuing the same with the ratio of the spaces to be described, all the points will arrive at the axis at the same time, and always depart from it at the same time. And therefore the curve A C D E B will be rightly determined. Q. E. D."

" Moreover the two curves A C D E B, and A  $\alpha \delta \epsilon B$ , being compared together, by *Lemma 1.* the curvatures in D and  $\delta$  will be as the distances from the axis D g and  $\delta g$ ; and therefore, by *Lemma 2.* the acceleration of any given point in the string will be as its distance from the axis. Whence, (by *Sect. 10. Prop. 51.* of Newton's Principia) all the vibrations, both great and small, will be performed in the same periodical time, and the motion of any point will be similar to the oscillation of a body vibrating in a Cycloid. Q. E. I."

" *Cor.* Curvatures are reciprocally as the radii of circles of the same degree of curvature. Therefore let  $a$  be a given line, and the radius of curvature in E will be equal to  $\frac{aa}{E n} .$ "

" *Prob. 2.* The length and weight of a string being given, together with the weight that stretches the string, to find the time of a single vibration."

" Let

good or bad. The contemporaneous expression of two of them is called a *consonance* or *dissonance*, according as it produces a pleasant or unpleasant effect. A single string may be made successively shorter

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“ Let the string be stretched between the points A and B, fig. 4. Plate XIV. by the force of the weight P, and let the weight of the string itself be N, and its length L. Also let the string be put in the position A F p C B, and at the middle point C, let C S, a perpendicular be raised, equal to the radius of the curvature in C, and meeting the axis A B in D; and taking a point p near to C, draw the perpendicular p c and the tangent p t.”

“ Therefore it appears, as in *Lemma 2*, that the absolute force by which the particle p C is accelerated, is to the force of the weight P, as c t to p t; that is, as p C to C S. But the weight P is to the weight of the particle p C, in a ratio compounded of the ratios of P to N, and of N to the weight of the particle p C, or of L to p C; that is, as  $P \times L$  to  $N \times p C$ . Therefore, compounding these ratios, the accelerating force is to the force of gravity, as  $P \times L$  to  $N \times C S$ . Let therefore a pendulum be constructed, whose length is C D; then (by Sect. X. Prop. 52, of Newton’s Principia) the periodical time of the string will be to the periodical time of that pendulum, as  $\sqrt{N \times C S}$  to  $\sqrt{P \times L}$ . But by the same proposition, the force of gravity being given, the longitudes of the *pendula* are in a duplicate ratio of the periodical times. Whence  $\frac{N \times C S \times C D}{P \times L}$ , or writing  $\frac{aa}{CD}$  for C S, (by Cor.

Prob. I.)  $\frac{N \times aa}{P \times L}$  will be the length of a pendulum, the

shorter and shorter, according to the proportions of the table; and thus a single string may express all the various musical sounds; but in this case, two sounds cannot be expressed at the same time.

In

vibrations of which are isochronous to the vibrations of the string."

"To find the line  $a$ , let the absciss of the curve be  $A E = z$ , and the ordinate  $E F = x$ , and the curve itself  $A F = v$ , and  $C D = b$ . Then (by Cor. Prob. 1.) the radius of curvature in  $F$  will be  $\frac{a a}{x}$ . But  $v$  being given, the radius of curvature is  $\frac{\dot{v} \dot{x}}{\ddot{x}}$ . Whence  $\frac{a a}{x} = \frac{\dot{v} \dot{x}}{\ddot{x}}$ , and therefore  $a a \ddot{x} = \dot{v} x \dot{x}$ ; and taking the fluents  $a a \dot{x} = \dot{v} x^2 - \frac{\dot{v} b^2}{2} + \dot{v} a^2$ . Here the given quantity  $= \frac{\dot{v} b^2}{2} + \dot{v} a^2$  is added, that it may be  $\dot{x} = \dot{v}$  in the middle point C. And hence the calculus being compleated, it will be  $\dot{x} = \frac{a^2 \dot{x} - \frac{1}{2} b^2 \dot{x} + \frac{1}{3} x^2 \dot{x}}{\sqrt{a^2 b^2 - a^2 x^2 - \frac{1}{4} x^4 - \frac{1}{4} b^4 + \frac{1}{2} b^2 x^2}}$ . Now let  $b$  and  $x$  vanish in respect to  $a$ , that the curve may coincide with the axis, and it will be  $\dot{x} = \frac{a \dot{x}}{\sqrt{b b - x x}}$ . Now, with the centre C, and radius D C =  $b$ , fig. 5. Plate XIV. a quadrant of a circle D P E being described, and making C Q =  $x$ , and erecting the perpendicular Q P; then the arch D P being =  $y$ , it will be  $y = \frac{b \dot{x}}{\sqrt{b b - x x}} = \frac{b}{a} \dot{x}$ ."

"Whence

In some instruments, as the forte-piano, harpsichord, &c. each string expresses a particular tone. In other instruments, such as the violin, violoncello, &c. each string is caused to express several tones successively, by stopping part of it with the fingers

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" Whence  $y = \frac{b}{a} z$ , and  $z = \frac{a}{b} y$ . And making  $x = y = CD$ , in which case it is also  $y =$  quadrantal arch  $DPE$ , and  $z = AD = \frac{1}{2} L$ ; it will be  $\frac{1}{2} L = a \times \frac{DE}{CD}$ , and  $a = L \times \frac{CD}{2DE}$ . Let it be therefore  $CD : 2DE ::$  diameter of a circle : circumference ::  $d : c$ ; and it will be  $aa = LL \times \frac{dd}{cc}$ . Therefore this value being substituted for  $aa$ ;  $\frac{N}{P} \times L \times \frac{dd}{cc}$  will be the length of a pendulum, which will be isochronous to the string. Therefore let  $D$  be the length, whose periodical time is  $t$ , and  $\frac{d}{c} \sqrt{\frac{N}{P} \times \frac{L}{D}}$ , will be the periodical time of the string. Q. E. I."

" For the periodical times of pendulums are as the square roots of their lengths."

*Cor. 1.* The number of vibrations of the string in the time of one vibration of the pendulum  $D$ , is  $\frac{c}{d}$   
 $\sqrt{\frac{P}{N} \times \frac{D}{L}}$ .

*Cor. 2.* Because  $\frac{d}{c} \times \sqrt{\frac{1}{D}}$  is given, the periodical

fingers, and permitting a certain portion only to vibrate.

*The Scale of Musical Sounds, or of the proportional Lengths of the Strings, which emit those Sounds, together with their Literal and Numerical Names, as also the Names of the Intervals between them; where T stands for Major Tone; t for Minor Tone; and H for Hemi-Tone.*

i	C	First	T
$\frac{8}{9}$	D	Second	t
$\frac{4}{5}$	E	Third	H
$\frac{3}{4}$	F	Fourth	T
$\frac{2}{3}$	G	Fifth	t
$\frac{3}{5}$	A	Sixth	T
$\frac{8}{15}$	B	Seventh	H
$\frac{1}{2}$	c	Octave	T
$\frac{8}{18}$	d	Ninth	t

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time of the string is as  $\sqrt{\frac{N}{P} \times L}$ . And the weight P being given, the time is  $\sqrt{N \times L}$ . And the strings being made of the same thread, in which case it is N as L, the time will be as L."

$\frac{4}{10}$	e	Tenth	H
$\frac{3}{8}$	f	Eleventh	T
$\frac{2}{6}$	g	Twelfth	t
$\frac{3}{10}$	a	Thirteenth	T
$\frac{8}{30}$	b	Fourteenth	H
$\frac{1}{4}$	C	Sixteenth, or Double Octave, &c. &c.	

This table might be continued to any length, and the law of continuation will appear from the following paragraphs, which will be found to contain the necessary explanations.

The fractions denote the relation of each string or tone to the first, or to the key, note. The length of the first string may be a foot, or a yard, or in short of any other dimension; but then the other strings must be made in due proportion to that length, which is called one or unity. For instance, if the first string be a yard long (viz. 36 inches) then the next string must be 32 inches in length; for 32 is equal to  $\frac{8}{9}$ ths of 36. This fraction likewise shews, that the second string performs nine vibrations, whilst the first performs eight vibrations. Also the length of the fourth string is marked  $\frac{3}{4}$ , meaning that it must be three-fourths of the first; and it shews, that this string

performs four vibrations whilst the first performs only three ; and so of the rest.

The letters which are annexed to the fractions in the second column of the table, are the names by which musicians distinguish the various tones ; and the numerical names of the third column, shew the distance of each tone from the first, which is otherwise called the *key-note*, or *principal tone*. Thus the fifth string is called G ; it is a fifth above the first, and its length is equal to two thirds of the first ; and so forth.

It must be remarked, that seven names, or letters, are given to all the tones ; viz. C, D, E, F, G, A and B to the first seven ; then the same names or letters are repeated in the same order for the next seven, and might again be repeated for a third set, a fourth set, &c.

By a closer inspection, it may be perceived, that the fractions, which express the lengths of the strings, are quite different from each other for the first seven notes only ; but after that they come again in the same order ; excepting only that for the next seven tones the fractions are the halves of the former respectively ; for instance, the length of the second C is  $\frac{1}{2}$  ; viz. the half of the first C ; the length of g is  $\frac{2}{3}$ ths ; viz. the half of G, which is  $\frac{2}{3}$ ds, &c. Farther, the third set of seven strings are the halves of the second set, or the quarters of the first ; and so on. The numerical names go on

increasing progressively; for they only shew the distance of each tone from the first; thus *c* is said to be an *octave* to *C*; *g* is said to be a *twelfth* to *C*, &c.

It is therefore evident, that seven are the principal tones of the musical scale. The next seven are said to be the *octaves* of the first; the next seven to those are said to be the *double octaves* to the first seven, &c. Therefore with respect to the peculiar nature of each tone, we need only examine one octave, viz. the first set of seven tones, together with the first tone of the next set.

The fractions of the table express the proportional lengths of the strings with respect to the first; but if the length of each string be compared with the string next to it, then it will appear that the intervals are not equal throughout the octave; but that there are three sorts of interval. Thus *C* (always meaning the string which expresses *C*, and the same of the rest) is to *D* as 9 to 8. *D* is to *E* as 10 to 9\*. *E* is to *F* as 16 to 15. *F* is to *G* as 9 to 8. *G* is to *A*, as 10 to 9. *A* is to *B* as 9 to 8; and lastly, *B* is to the *C*, next to it, as 16

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\* In order to make the above-mentioned comparison, the fractions must be reduced to a common denominator; then the ratio of their numerators must be expressed in the lowest integral terms; thus  $\frac{9}{8}$  and  $\frac{8}{7}$  reduced to a common denominator, become  $\frac{63}{56}$  and  $\frac{64}{56}$ ; then 49 is to 36, as 10 is to 9.

to 15. The intervals farther on are equal to the former, and come in the same order.

By inspecting the preceding paragraph, it will appear that those intervals are of three sorts, viz. the interval of 9 to 8, the interval of 10 to 9, and the interval of 16 to 15. The first of those intervals has been called a *major tone*; the second has been called a *minor tone*; and the last has been called an *hemitone*\*.

The intervals which form an octave, are disposed in the following order, viz. major tone, minor tone, hemitone, major tone, minor tone, major tone, and hemitone; which may be expressed by their initials, as in the fourth column of the table in p. 372, viz. T, t, H, T, t, T, H. Whence it appears, that a fifth, or the interval between C and G, contains two major tones, one minor tone, and an hemitone; also a fourth, or the interval between C and F, contains a major tone, a minor tone, and an hemitone, &c.

If it be asked why are the intervals disposed in the above-mentioned order, and why is C considered as the first or fundamental note? The answer is, that repeated experience has shewn, that this order produces a pleasing musical melody, and that the C is called the fundamental, or key-note, or the first

\* The difference between a major and a minor tone, i.e. between  $\frac{9}{8}$  and  $\frac{10}{9}$ , which is the interval of 81 to 80, has been called a *comma*.

of that order of intervals; because the melody generally begins, and almost always ends with that note; besides, the rules of composition, and the arrangement of the various periods of the melody, always have a reference to that key-note.

In the table of page 372, there is, however, another tone, which may be taken for the principal or key note, and that is A; but the intervals in the octave, from A to a, are in the following order, viz. T, H, T, t, H, T, t, which order differs from the other, principally in its having the interval of the third, and the interval of the sixth, smaller than in the other order; hence this order is called the *flat mood*, or the key of A with a flat third; whereas the other is called the *sharp mood*, or the key of C with a sharp third.

Nature seems not to admit of any other order of intervals fit for music; therefore, in the natural scale, as expressed in page 372, no other note may be taken for the principal or key-note; so that no piece of music could be written in any other key besides C or A. But the ingenuity of musicians has contrived to multiply the key notes, or rather to render every tone capable of being considered as the key note of a sharp as well as of a flat mood; and this object has been accomplished by the interposition of certain intermediate tones between those of the natural scale, which are to be used occasionally, and which have no particular name or letter; but derive their appellations from

the neighbouring principal notes ; thus a certain sound, interposed between C and D, is called either C sharp, or D flat : another interposed between D and E, is called either D sharp, or E flat ; and so of the rest. It must be remarked, however, that between E and F, as also between B and C, no other sound is interposed, because the intervals between those notes are already very small, there being only an hemitone between each pair.

The nature and the use of those intermediate sounds, which are commonly called *flats* and *sharps*, will appear from the following example and explanation.

If, instead of C, a person wished to make F the key note ; then the proper order of intervals either for a flat, or for a sharp mood, must take its commencement from F.—Suppose it be required to be a sharp mood, in which case the intervals must be T, s, H, T, s, T, H. Now, by observing the table in page 372, it will be found that there is, as it ought to be, a major tone between F and G, a minor tone between G and A ; but between A and B there is a major tone ; whereas there should be an hemitone ; therefore in order to remedy this defect, another string is interposed between A and B, of such a length as may express a proper fourth to F ; and this intermediate sound is called B flat, or A sharp : then between this B flat, and the next C, there is a major tone, which is right ; and so are likewise the following intervals. So that

when

when F is to be reckoned the key note, we must then use B flat instead of B natural.

After the same manner it may be easily shewn that when any of the other notes is taken for the key note, there needs be interposed flats or sharps between some of the other natural or primitive sounds, &c.

In short, by the interposition of one sound between any two contiguous tones of the natural octave, except between E and F, as also between B and C, the whole octave is caused to contain 12 intervals; and by this means every one of those 12 sounds may be taken for the key note of a sharp or a flat mood, and is called accordingly; for instance, the key of D with a sharp, or with a flat, third; the key of E with a sharp, or with a flat, third; the key of E flat, with a sharp third, or the key of E flat, with a flat third; and so of the rest.

Yet this disposition of tones, both principal and intermediate, is attended with a remarkable imperfection, which may be palliated, but cannot be entirely removed. — The nature of this imperfection will be shewn in the sequel; but previously to it, something must be laid with respect to the notation of the various musical sounds.

The whole range of musical sounds, comprehending all those which may be expressed by human voices, as also by the musical instruments that are mostly in use, consists of about seven or eight octaves;

octaves; yet musicians can express every one of those sounds by placing certain spots, marks, or notes, upon, and adjoining, five parallel lines; and, in fact, music paper is ruled with such zones of parallel lines.

A mark or note, placed upon one of those lines, denotes a certain tone; for instance C, a mark placed in the space which is between that line and the next above, denotes the next note to that, viz. D; a mark on the next line above, denotes E; and so forth. The intermediate sounds, or the flats and sharps, are denoted by auxiliary marks, viz.  $\sharp$  denotes a sharp, and  $\flat$  denotes a flat; thus  $\sharp$  prefixed to the note of D, means the sound intermediate between D and E; and  $\flat$  prefixed to the note of E, means the same sound, viz. the sound intermediate between D and E, &c.

The form of the notes, viz. whether the mark is entirely black, or open like an o, or having a tail annexed to it, has nothing to do with respect to the particular sound. That diversity of form indicates the duration only of the sounds; or what is called the time.

By inspecting any one of the zones in fig. 6. Plate XIV. it will be perceived that, upon the usual five lines of music, no more than eleven different notes can be marked, viz. one upon each line, one upon each of the four spaces between those lines, one above the upper line, and one below the first

line:

line: at present, indeed, the notation is extended considerably above and below the five lines, and that by means of auxiliary little lines, as in fig. 7-Plate XIV. ; yet this last-mentioned method is by no means sufficient to express the whole range of musical sounds. Formerly, however, they used only the eleven notes of fig. 6 \*. Now, in order to express the higher or lower tones, the names and signification of the notes are altered, and this alteration is indicated by a certain mark, called *clif*, which is always placed at the beginning of a piece of music, and likewise wherever the value of the notes is required to be altered.

There are seven of those cliffs. (See fig. 8. Plate XIV.) They are of three different forms, and of three different significations, viz. the first two are called cliffs of F, because where they are placed, (viz. on the fourth line and on the third line) there the note of F is situated, and the other notes above and below are named accordingly. The four cliffs of the second species are called cliffs of C, because where they are situated, viz. upon four of the five lines, there the C is placed. Of the

\* The ancient masters of music reckoned a good voice for singing, whether base, or tenor, or treble, &c. that which could express eleven good and pleasant tones. In fact, very seldom a singer can go higher or lower, without changing the quality of his voice. Hence eleven principal marks were reckoned sufficient for musical notation.

third species there is but one cliff, which is called the cliff of G, because where that cliff is situated, viz. on the second line, there the note of G is placed.—Those cliffs, besides the specific names, have each a peculiar appellation. The peculiar appellations of those cliffs, together with the names or significations of the notes in each cliff, are clearly exhibited in fig. 6. Plate XIV. wherein the notes, for brevity sake, are not carried on farther above or below the eleven above-mentioned notes\*.—Should the reader be desirous of learning which note of one cliff corresponds with a certain other note of the other cliffs, fig. 9. Plate XIV. will give him the required information; for in that figure, a note is placed after every one of the seven cliffs, and every one of those notes indicates the same sound precisely; namely, the C, which is expressed by placing the third finger upon the fourth or largest string of a violin.

Hitherto we have only mentioned the dependence, or rather the ratio that one sound bears to another; so that when one sound is given, its fifth, or third, or octave, &c. may be easily found; but it will be necessary to define or determine the first, or any one of them, since from one being known, all the others may be derived. The conveniency of singers has established a certain standard, which is

\* At present, however, the baritone cliff, and the half soprano cliff, are seldom, if ever, used.

adopted by most musicians in this country; is used in concerts, as also at the opera house, play houses, &c. It is called the *concert pitch*; and this sound is expressed by a small instrument, which is conveyed from place to place by those persons who tune organs, harpsichords, &c. It is a steel instrument, which when struck sounds a certain note. See fig. 11. Plate XIV. or else a little sort of flute, which sounds that certain note. Those *tuning forks*, or *tuning pipes*, (for so they are called) are tuned all alike, after a pattern one, which is kept in reserve by the makers; and indeed, notwithstanding the wear and alteration by heat and cold, those tuning forks are in general pretty much of the same pitch. According to that pitch, the C, which follows the cliff in fig. 9. performs about 513 vibrations in one sound.

Fig. 12. of Plate XIV. exhibits in one view all the particulars which may be of use with respect to an octave of tones, hemitones, &c. It consists of 6 horizontal rows. The first row contains the 13 notes of an octave expressed in the base cliff. The second row shews the ratio of the string which expresses each sound, with respect to the first. The third row expresses the lengths of the various strings, (which must be equal in all other respects) in numbers of equal parts, of which 3600 are equal to the length of the first string. The fourth row expresses the actual number of vibrations performed in one second by each sound, ac-

cording to the concert pitch \*. The fifth row contains the literal names; and the sixth row contains the numerical names of the sounds, when C is the first, or key, note.

Hitherto we have only spoken of the succession of sounds, and have asserted that the sounds only of the scale, which is stated in page 372, can furnish a

\* Those numbers of the vibrations, &c. have been deduced by calculation, according to the rule in page 362; wherein the resistance of the air is not noticed; hence they probably are a little higher than the truth.

For this purpose a brass harpsichord string was suspended like a pendulum, with a weight of 5 lb. and 14 ounces (viz. 41125 grains) at its extremity. The length of the string was 62 inches, its weight was 22,25 grains. Its sound, according to the concert pitch, was exactly A, viz. one octave below the A, in fig. 12. By calculation, from those data, it was determined to perform 107 vibrations in one second.

Heat and cold have a considerable influence on the pitch of all sonorous bodies, which arises from their being expanded or contracted in their dimensions, also from an alteration of their elasticity. A steel tuning-fork, heated to the degree of boiling water, will sound a note about a hemitone lower than it will when cooled to the degree of freezing water. The pitch of an organ pipe will be higher in summer than in winter; for in that pipe it is the column of air that vibrates; and in the winter time that column of air is denser, heavier, and of course vibrates slower, than in summer. See Smith's Harmonics, Sect. IX. Schol. to Prop. XVIII.

pleasing

pleasing melody, or rather the most pleasing melody. But it is necessary to observe, that the propriety of such sounds is shewn likewise by the agreement, or pleasing effect, which arises from certain two or more of them being expressed at the same time ; and it is remarkable that the like pleasing effect cannot be produced by any other scale of sounds.

When two sonorous bodies, that express the same note precisely (in which case they are said to be in *unison*) are sounding at the same time ; the agreement is so great, that we can seldom perceive whether it be one sound or two. The next best agreement is when any note, and its octave, are sounded at the same time. Next to this is that of any note and its fifth ; then that of any note and its third sharp, and then that of any note and its third flat, or its sixth, either flat or sharp.

A *perfect accord* is that which arises from four notes expressed at the same time, viz. any note, its third sharp, its fifth, and its octave. The other accords are *imperfect* ; and some of them are very disagreeable ; yet with certain restrictions some of them are not only tolerable, but may be introduced with considerable effect.

The rules of musical composition, which direct the proper arrangement of accords, and likewise shew the necessary limitations or management of the melody, have been deduced from long and diversified experience. Upon the whole, they are rather

intricate and numerous ; but notwithstanding their multiplicity, the various cases and combinations of musical sounds are far from being all reduced, and seem not to be all reducible, to certain and determinate rules. In musical composition, a great deal must depend upon the genius of the composer; and this genius, or natural disposition, to invent pleasing melodies, and pleasing harmony, is what principally distinguishes one composer from another. It is the gift of nature ; it may be guided, but not given, by art.

It has been said above, that the disposition of tones and hemi-tones, such as is exhibited in fig. 12. Plate XIV. is attended with a remarkable imperfection, which may be palliated, but cannot be entirely removed. — The nature of this imperfection will be easily manifested by means of an example.

The proportional, as well as the proper lengths of the strings, which express the 2d, 3d, 4th, 5th, &c. of C ; viz. when C is taken for the key note, are expressed in fig. 12. But suppose it be required to make, not C, but D, the key note ; then A, which was the sixth of C, does now become the 5th of the key note D ; and therefore its length must be two-thirds of the length of D. Now, in the table, the length of D is 3200 equal parts, and that of A is 2160 such parts ; but 2160 is not equal to two-thirds of 3200 (for  $\frac{2}{3}$  of 3200, are 2133 $\frac{1}{3}$  &c.) ; therefore the A in the scale,

which

which is a proper sixth to C, is an imperfect 5th to D; nor can this deficiency be supplied by the interposition of another string between A and A sharp; because that other string, though a perfect fifth to D, would be an imperfect fourth, when E is taken for the key note, or it would be an improper 3d, when F is taken for the key note, &c. And if so many strings were interposed between A and A sharp, as to supply all those deficiencies, the complication and multiplicity of sounds would be endless; for what has been said of A may, with equal propriety, be said of every other sound of the octave.

The only expedient which is at present practised for the purpose of palliating the above-mentioned imperfection, is to tune the A not so high, or to make the length of that string not so long as 2160 parts, nor so short as 2133,3, by which means that A is rendered an imperfect sixth to C, and an imperfect fifth to D; or the imperfection is divided, which renders it tolerable in both cases, otherwise it would be very pleasant in one case, but intolerable in the other. The same thing is done with respect to all the other sounds of the octave; viz. they are made to deviate a little from those proper pitches, or from the lengths, which are expressed in fig. 12. for the purpose of rendering them tolerable when one note or another is taken for the key note. This deviation from the proper lengths, or from the proper pitches, is called the *temperament*.

of musical instruments, or of the musical scale ; and is used in tuning all those instruments which have fixed notes, as the harpsichord, organ, &c. And even with other instruments, and with the voice in singing, a certain temperament is used, both from imitation and from necessity \*.

It must be observed, with respect to this temperament, that if the imperfections be divided equally, viz. in such a manner as to render the effect the same, whether one or another of the 12 sounds of the octave be considered as the key note ; then that effect would not be pleasant ; therefore the practice is to divide the imperfections, but to divide them *unequally* ; viz. so as to render the second, third, fourth, fifth, &c. of some key notes, in which most pieces of music are written, less imperfect than others.

An equal temperament, therefore, is impracticable ; and it is impossible to fix the limits of an unequal one, or such as may be commonly used ; for almost every tuner of instruments uses a temperament a little different from the rest, of which he judges by his hearing only ; and some capital performers sometimes have their instruments tuned with a peculiar temperament, for the purpose of

\* For the nature and limits of the temperament of musical instruments, see my paper on the subject in the 78th vol. of the Philosophical Transactions.

giving a greater effect to their particular compositions \*.

We shall, lastly, conclude this long chapter with some remarks concerning the effects which are attributed to musical sounds. Of those effects there are some which are true and acknowledged ; whilst others are less conspicuous, or doubtful, and perhaps absolutely chimerical.

Single sounds, or a succession of sounds, are pleasant or unpleasant in various degrees. The single sounds, in order to be pleasant, must be uniform; neither too loud nor too soft, and must be as simple as possible. A regular swell and decay in the strength of the sound is pleasing in certain cases ; but it is impossible to define the quantity of those qualities,

The various tones of a natural voice, or of an instrument, should be of one quality ; whereas they frequently seem to belong to different voices, or to different instruments †.

If

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\* I have a set of tuning-forks, for all the 13 sounds of an octave, which were tuned by one of the best piano-forte makers in town, according to his temperament ; but on comparing them with instruments recently tuned by other persons, I find that they very seldom, if ever, agree perfectly together.

† The strings of piano-fortes, harpsichords, &c. were they all of the same thickness, could not conveniently be made of the proper lengths ; therefore, by making them of

It is impossible to say whence arises the pleasure which is communicated by certain successions of sounds. There are certain periods in musical melody which excite peculiar sensations more or less pleasing, and produce different sensations of pleasure or displeasure, upon different persons. Those sensations cannot be expressed or defined.

The agreement or disagreement of two or more sounds, expressed at the same time, seems, upon the whole, to arise from the more or less frequent coincidence of the vibrations. Thus any tone and its octave, agree better than the same tone and its fifth, the latter better than the same tone and its third, &c. viz. the compound sound is smoother, and approaches nearer to the nature of a single sound in the first case; less in the second; still less in the third, &c. And, in fact, in the first case there is a coincidence of vibrations at every second vibration of the grave tone; the coincidence is not so frequent in the second case; still less in the third, and so on; yet the more or less pleasant or unplea-

different sizes, and by stretching them differently, their lengths are suited to the commodious size of the instrument. Now the great object in adjusting the sizes and lengths of such strings, is to contrive that each string be stretched by a force proportionate to its thickness and length; otherwise the instrument will not have a uniform voice.— Few makers of such instruments pay sufficient attention to this particular.

sant effect, cannot arise entirely from that more or less frequent coincidence; for (besides other reasons which, to avoid prolixity, shall not be mentioned here) in the first place, a succession of thirds or of sixths is much more pleasant to the ear than a succession of fifths; and, in the second place, the introduction of a discord in certain accords, is not only tolerable, but very pleasing. The cases in which discords may be introduced, have been found by experience, and are specified amongst the practical rules of musical composition, which do not belong to this treatise.

It has been said above, that seldom, if ever, a sounding body expresses a single sound; and that such sounding bodies are used in music as express the simplest sounds. But even amongst those, some singular productions of secondary sounds have been remarked, and the principal facts are as follows:

If a large string of a musical instrument be sounded, or, in short, if a pretty deep and rather strong sound be continued for a little time, there will be heard at the same time two other sounds; namely, the 12th and the 17th of the original sound. For instance, if the lowest C in the base cliff be sounded, you will hear the second G and the third E of the scale above.

It was discovered by Tartini, at Ancona, in the year 1713, that if of the three notes which form the perfect accord of 3d, 5th, and octave, (as for

instance C, E, and G; or G, B, and D, &c.) two be sounded at the same time, a third sound will be heard, viz. a fundamental note \*.

The various cases of this sort are shewn in fig. 10. Plate XIV. where the open notes are those which must be sounded (and here it is to be observed, that they must be sounded perfect, viz. without temperament), and the black note is the sound which is heard. The first case is evidently the reverse of that which is mentioned in the paragraph last but one. In the last case, the note which is heard is in unison with one of those which is sounded; but it may be distinguished by its being a sound of different quality.

The true reason of those phenomena is not known; nor shall I detain my reader with any account of the insufficient hypotheses that have been offered for their explanation. Certain it seems, that the third sound is not produced by the undesigned communication of the vibrations to some other string or pipe of the instrument; for if you take a violin, and sound at the same time C on the largest string, and A on the next, you will also hear an F, which is a 12th below the C, and which cannot be expressed upon any string of the violin; G being the lowest note of that instrument.

\* See Tartini's Treatise, *della vera scienza dell' Armonia.*

Frequent mention is made by the ancient writers, as also by modern enthusiasts, of the wonderful effects of music on the passions. Anger, compassion, love, melancholy, cheerfulness, &c. may in some measure be excited by music ; but the concurrence of other circumstances, the exaggeration of the accounts, and the various sensibility of individuals, will not allow us to settle the standard of credibility upon any sure foundation. The ancients, under the name of music, comprehended poetry and dancing ; and we may easily believe that fine poetry set to music in a simple melody, and perhaps accompanied with dancing, or with actions, may have had considerable effect on the fancies and affections of different persons, especially of those to whom it arrived new.

With respect to the effects of modern music, which is undoubtedly more refined than the mere music of the ancients, most, and perhaps all, of my readers are able to judge for themselves.

Amongst the extraordinary effects that have been ascribed to music, its affording a cure for the poison of the Tarantula spider, has been so frequently asserted, that it would appear improper to leave the story quite unnoticed in this chapter.

In the southern part of Italy, especially in the south of Naples and in Sicily, sometimes persons, almost always of a low condition, are bit by a

largish sort of spider, called *tarantula*. At certain periods of the year the person that has been once so bit, asserts to feel a pain about the part bit, which is accompanied with dejection of spirits, sallowness, &c. If sprightly music be playcd (and a certain jig, called the *tarantella*, is generally played on such occasions) the patient gets up, and begins to dance with irregular gestures ; the quickness of his movements generally increases to a certain degree ; and the dance continues sometimes without intermission for hours. At last the patient, fatigued and exhausted, throws himself down on the floor, or on a chair, or a bed, &c. to recruit his strength ; and the fit is over for that time.— The remarkable part of the story is, that this exertion of dancing, &c. cannot be done without music.

In the first place, it is very doubtful whether the spider is at all poisonous, or whether it has any share at all in the production of the pretended illness.

The disorder, probably a nervous or hysterical affection, may arise from other causes, especially in a pretty warm climate. And the violent agitation of the patient, accompanied with perspiration, &c. may, very likely, relieve him or her. (for the tarantula bites women as well as men.)

The pretended indispensable aid of music, the long continuance of the dance, the strange ges-  
tures,

tures, and several odd fancies, which such patients are supposed to have, are, in all probability, dictated by prejudice, by the love of singularity, or by the desire of exciting astonishment in the minds of the spectators, who are always numerous on such occasions.

## CHAPTER XIII.

A GENERAL VIEW OF THE PRINCIPAL USES OF  
THE ATMOSPHERE; WHEREIN THE NATURE OF  
RAIN AND EVAPORATION WILL BE NOTICED.

THE aerial fluid which surrounds the earth, and whatever exists thereon, is unnoticed by the vulgar, amongst whom the words *air* and *nothing* are almost synonymous; it is considered as a superfluous appendage by the superficial observer; but the deepest researches of the most enlightened philosophers, acknowledge the infinite wisdom of nature, in the creation of a fluid most indispensably necessary for the maintenance of animal and vegetable life; for the dispersion of light; for the communication of sound; for the absorption of water from certain places, and the dispersion of the same fluid over other places; for giving motion to a variety of useful machines, &c.

There is not one of the properties of the air, nor one of its movements, however trifling or irregular it may at first sight appear, which, when duly considered, will be found to be useless or defective. Were the air either lighter or heavier; had it a different degree of elasticity, than it does now possess,

, were its other properties at all altered, theism of the terraqueous globe would be de-d, and perhaps utterly destroyed.

e same incomprehensible wisdom that has ar-  
d all the parts of the universal frame in due  
ts and proportions, may undoubtedly fit them  
ifferent sort of atmosphere by a suitable altera-  
of the whole state of things ; but our very li-  
l comprehension, not being able to conceive  
such an alteration could be made for the better,  
finds ample reason for satisfaction, admiration,  
wonder, in the investigation of the properties of  
existing atmosphere.

ster having admired the general order, and the  
idential wisdom of nature, it will be necessary  
amine, with patient toil, what more immedi-  
concerns us, viz. the particular uses of the at-  
phere, at least as far as may be inserted in this  
; for we must necessarily reserve the chemical  
erties of air, and its connection with light, heat,  
electricity, for the subsequent parts of this  
c.

is in consequence of the weight and elasticity  
he air, that animals respire with freedom, and  
the operations of sucking, pumping, &c. are  
ormed.

he thorax, or that part of the human body  
h is surrounded by the spine or back bone,  
ribs, the sternum or breast bone, and the dia-  
igm, is almost entirely occupied by the lungs,  
which

which consist of an immense number of vesicles, whose cavities communicate with certain ducts, and those ducts, with others of a larger size, which at last communicate with a large one, called the *wind pipe*, the aperture of which is in the mouth, at the back or root of the tongue.

The air, unless we keep both the mouth and the nostrils closed, communicates with the inside surface of the lungs; that is, of its innumerable vesicles, and with the outside of the thorax or chest. If we enlarge the chest, the weight of the atmosphere drives a quantity of air in our lungs, which is called *an inspiration*; and if we contract our chest, a quantity of air is expelled from it, which is called *an expiration*.

The enlargement of the chest is occasioned by an elevation of the ribs, by a small motion of the sternum, and by a suitable movement of the diaphragm; but the action of each part cannot be understood without a particular anatomical description, which does not belong to this treatise.

The freedom of respiration in a sound animal body, depends on the equal pressure of the atmosphere, both on the inside surface of the lungs, and on the outside of the body. In fact, if we keep both mouth and nostrils accurately closed, we can neither contract nor expand our chest; excepting, indeed, in a small degree; for the quantity of air which always remains within the lungs,

may

may be a little rarefied, or compressed, by the exertion of our muscles.

A man usually performs about twelve inspirations, and as many expirations in a minute; but respiration may be quickened by various causes, as by agitation of the body or mind, by heat, by a rarefied or vitiated atmosphere, and by diseases. Infants breathe quicker.

In general, a full grown person takes in between 20 and 30 cubic inches of air at every inspiration, and expels about the same quantity at every expiration, but a great deal of air does always remain in the lungs. In a forced or violent inspiration, or expiration, a double quantity of air, viz. about 50 cubic inches of air, may be taken in or expelled, and even then a considerable quantity of air remains in the lungs, besides what is contained in the mouth, wind pipe, &c. for the capacity of the lungs of a man, may at a mean be reckoned equal to about two cubic feet.

The operation of sucking, in general, consists in removing the pressure of the atmosphere from a certain part of the surface of a fluid, whilst that pressure is at liberty to act on some other part of the surface of the same fluid, in consequence of which the fluid is forced to ascend where the pressure has been removed or diminished.

If a man apply his mouth to the aperture of a bottle full of liquor, and standing straight up, he will not be able to suck any liquor out of it; but

if a hole be opened at the bottom of the bottle, and that bottle be set in a basin full of liquor, then the liquor may be sucked out of it. And the same effect will take place if an open tube be set with one end in water, and a man apply his mouth to the other end, and sucks. The mechanical part of the operation is as follows : — By enlarging his chest, the man rarefies the air, and, of course, diminishes its pressure on the liquor, which is immediately under the tube ; in consequence of which the pressure of the atmosphere on the surface of the surrounding liquor, forces the liquor to ascend into the tube. (See the experiment, which is described in page 205.)

In the operation of sucking, after the manner of children, the rarefaction is produced in the fore part of the mouth ; viz. the tongue is applied so as to fill up the space between the lips and the nipple, or pipe which conveys the milk or other liquor ; then the tongue is drawn backwards, whilst the lips are laterally pressed against it, by which means a little vacuum is formed before it, and the liquor is forced into that vacuum by the pressure of the atmosphere upon its external surface, or upon the surface of the bag which contains it.

If an empty vessel, having one aperture, be applied with its aperture to the lips, and the above-mentioned operation of sucking be performed, the vessel, if not too heavy, will remain attached to the lips, and that for the same reason.

It is for the same reason, that snails remain attached to solids, that limpets adhere very firmly to rocks, that the sea polypus holds with great force whatever it fastens its claws to, and that some insects suspend themselves to solids; for though not performed with the mouth, the principle of the operation is exactly the same, viz. a soft membrane is applied to the solid, then the middle part of that surface is withdrawn a little way, so as to form a vacuum, or at least a rarefaction of the air between the centre of the soft membrane and the solid, in consequence of which the parts of the membrane which surround that spot, are by the gravity of the atmosphere pressed against the solid, and the latter is pressed against the former; hence the adhesion takes place.

Leather suckers, which act precisely upon the same principle, are not unfrequently seen in the hands of boys about the streets of London. A circular piece of thick leather, about two inches in diameter, has a string, fastened to its centre. The leather being previously well soaked in water, is applied flat and close to the smooth surface of a stone. The interposition of a little water promotes the adhesion. Then the boy pulls up the string, and the stone, if not too heavy, comes up adhering to the leather.

The claws of the polypus are furnished with a great many suckers of the like nature. The limpet forms one sucker of its whole body, and the same

thing, with little variation, is done by various other animals, especially of the insect tribe.

The action of the glass cup, which is made to adhere to the flesh, for the purpose of bleeding, depends upon the same principle ; excepting that the air, within the glass cup, is rarefied by means of heat, or by means of a small exhausting engine.

It is hardly needful to add, that the limpet could not adhere to the rock, nor could the leather sucker act, or, in short, that none of those sucking operations could take place, *in vacuo*.

The principal advantage which is derived from the vibratory movement of the air, is the propagation of sound, which could not be accomplished by other means ; for though sounds are conveyed by several other bodies better than by air ; yet in common affairs other bodies are neither to be found, nor can they be applied between the sounding bodies and our ears : whereas the air, by surrounding the whole earth, and whatever exists upon it, is always ready to convey sounds of any sort, and in every direction.

The progressive motion of the air is also of immense and indispensable use. The winds, so general, so frequent, and so various, besides the more obvious effects of driving ships, windmills, &c. preserve, by mixing, the necessary purity of the atmosphere. The air is contaminated by animal respiration, by fermentation, and putrefaction of animal and vegetable substances, as also by other processes;

processes; on the other hand it is purified by vegetation in certain circumstances, by agitation amongst aqueous particles, and probably by other means. Now it is owing to the winds that the impure portions of the atmosphere are mixed with the more purified parts of it; and that a proper mean is preserved. The winds likewise drive away vapours, clouds, fogs, and mists, from those parts in which they are copiously formed, to others which are in want of moisture; and thus the whole surface of the world is supplied with water. But it will be necessary to take a more particular notice of what relates to evaporation and rain.

When water is left exposed to the ambient air, the quantity of it will be gradually diminished, and after a certain time, the whole of it will disappear. The water in this operation is reduced into an elastic fluid, and is gradually dispersed throughout the air.

If a small drop of water be placed in a large glass bottle full of pretty dry air, the drop of water will disappear after a certain time, especially if the bottle be placed in a warm place. And if afterwards the same bottle be cooled, the water will thereby be separated from the air, and may be seen adhering to the inside surface of the bottle.

Heat promotes, and cold retards, evaporation; but even a piece of ice has been found to evaporate, and to be diminished in weight, whilst the atmosphere is actually in a freezing state.

Winds, or agitation, promotes evaporation.

If a quantity of water be placed in vacuo, viz. if it be placed under the receiver of an air pump, in the common temperature of the atmosphere, and the air be exhausted, a very small portion of the water will expand itself through the receiver, after which the quantity of water will remain unaltered. If the pumping be continued, the water will be diminished a little more; for as part of the steam is extracted from the receiver, a little more steam is separated from the water; but, upon the whole, the water will by this means be diminished in quantity very little indeed. On re-admitting the air into the receiver, the above-mentioned vapour is again condensed almost entirely into water.—Heat promotes the evaporation in vacuo.

Water then may exist in air; 1st, in an invisible state, which is the case when the dissolving power of air is considerable; 2dly, in a state of incipient separation, in which case it forms *clouds*, *mists*, or *fogs*; 3dly, and lastly, in a state of actual separation, in which case it forms either *rain*, properly so called, or *snow*, or *bail*.

*Clouds* are those well known assemblages of vapours that float in the atmosphere; have different degrees of opacity, which arises from their extent and density; and generally have pretty well defined boundaries. Their height above the surface of the earth (I mean not above the mountains) is various, but hardly ever exceeds a mile or a mile and a half.

In hot weather, or hot climates, the clouds, being more rarefied, are lighter, and ascend much higher than they do in colder climates, or colder weather: and indeed, in cold weather the clouds frequently touch the very surface of the earth; for a fog may with propriety be called a cloud close to the ground.

A *mist* is a very indefinite word. It means an incipient formation of clouds, or haziness; and it often denotes a very small rain, or a deposition of water in particles so small as not to be visible singly.

The *snow* is formed when the atmosphere is so cold as to freeze the particles of rain as soon as they are formed, and the adherence of several of those particles to each other, which meet and cling to each other as they descend through the air, forms the usual fleeces of snow, which are larger, (since they are longer in descending, and have a greater opportunity of meeting) when the clouds are higher than when they are lower.

The *hail* differs from snow in its consisting of much more solid, and much more defined pieces of congealed water. It is supposed that the water, already formed into considerable drops, is driven and detained a considerable time through a cold region of the atmosphere, by the wind, which almost always accompanies a fall of hail. But the globes of ice, or *hail-stones*, in a fall of hail, sometimes far exceed the usual size of the drops

of rain\*; which shews that by the action of the wind, the congealed particles must be forced to adhere to each other; and, in fact, though the small hail-stones are more uniformly solid and globular, the large ones almost always consist of a harder nucleus, which is surrounded by a softer substance, and sometimes by various distinct pieces of ice, just agglutinated. Their shape is seldom perfectly globular.

If a vessel of an uniform shape, and full of water, be exposed to the ambient air, and the decrease of water in it be measured at the end of every day, or month, or year, or, in short, of any given period, the evaporation which has taken place through that period may be ascertained; and it is generally expressed by the number of inches and tenths: thus, if it be said that the evaporation of a certain pond in one month be 10 inches, the meaning is, that 10 inches depth of water are evaporated in one month; or, that if the water which has been evaporated from it in one month might be collected and placed in a

\* Accounts of hail-stones of a very large size may be met with in almost all the works of natural philosophy, in several periodical works, in accounts of voyages, &c. I have been assured by creditable eye-witnesses, that in the island of Sicily hail-stones have sometimes measured more than three inches in circumference. Dr. Halley gives an account of hail-stones that weighed 5 ounces each. It is no wonder then that falls of hail sometimes demolish glasses, kill several animals, and destroy fruit, grain, &c.

vessel with straight up-sides, and having an horizontal surface equal to the surface of the pond, the collected water would fill 10 inches depth of that vessel.

If a vessel for measuring the evaporation be left long exposed, the surface of the water will descend a considerable way below the edge of it, in which case the subsequent evaporation would be retarded. This indeed might be remedied by the addition of certain quantities of water at stated times; but there is another inconvenience attending it, which is, that insects, dust, &c. fall in it, and thicken or cover the water. Therefore, the best way is to note the evaporation either every day, or whenever it may be convenient, but to clean the vessel, and to change the water in it at short intervals; for instance, once a week at least. A vessel fit for such purpose ought to have an aperture not less than 8 or 10 inches in diameter.

The quantity of evaporation from the surface of the sea or of the land, has been estimated in certain places only by a few scientific persons; but their estimates are seldom to be depended upon. General deductions, for extensive tracts, from partial, small, and sometimes equivocal, experiments, cannot afford much satisfaction, especially when the results of the experiments disagree from each other.

The quantity of evaporation is various in different spots. The surface of water furnishes upon the whole the greatest quantity of vapour; the

land more or less, according as it is marshy or rocky, or covered with vegetation, &c.

In hot climates, the evaporation is incomparably greater than in those which are colder. The evaporation from places that are much exposed to the wind and the sun, is likewise greater than from other places.

It was observed in London, by Dr. Halley, that the evaporation of water, situated in a room, out of the influence of the sun and of the wind, amounted, in one year, to 8 inches. It was his opinion also, that by the influence of the wind, the quantity of evaporation would have been trebled, and that this again would have been doubled by the influence of the sun. Upon the whole, he reckons the annual quantity of evaporation for London, at 48 inches\*. —Probably too great.

Dr. Hales estimates the annual evaporation from the surface of the earth only in England at 6,66 inches †.

Dr. Dobson deduced from a mean of accurate experiments made by himself during four years, that the annual evaporation from the surface of water at Liverpool, amounts to 36,78 inches ‡.

\* Phil. Trans. N. 212.

† Veg. Stat. vol. I.

‡ Phil. Trans. vol. 67th, for 1777. The quantity of evaporation for each of the four years, was as follows: 1772. 35,95 inches; 1773. 34,59 inches; 1774. 36,64 inches; 1775. 39,96 inches.

It has been calculated, that in one summer's day, about 5280 millions of tuns of water, are probably evaporated from the surface of the Mediterranean\*. It has also been calculated (omitting the great uncertainty to which such calculations are liable) that all the rivers, or at least the nine principal rivers, which discharge their waters into the Mediterranean, do not furnish more than 1827 millions of tuns of water per day †. The deficiency is undoubtedly supplied by the rain, which falls upon the same sea, and by the current which is constantly running from the Atlantic ocean into the Mediterranean through the straits of Gibraltar.

It may naturally be enquired by what means water, which is so much heavier than air, is converted into a fluid so light as to float in air; and how does it remain suspended and dispersed therein, sometimes without the least tendency to separation.

Various hypotheses have been offered in explanation of this subject; but I shall not detain my reader by the account of opinions that are always insufficient, and frequently absurd. The most remarkable facts, which may assist the inquisitive mind in the investigation of the subject, are as follows :

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- The vapour of sea water does not take up any saline particles.

If the steam of water be examined by means of lenses or microscopes, no regular bodies or configuration of particles will be distinguished in it.

There is an evident attraction between water and air, viz. the attraction of cohesion \*. If a small bubble of air be introduced in a glass vessel filled with boiled water, and inverted in water, that quantity of air will disappear in a day or two.

Heat, which diminishes the attraction of aggregation between the particles of water, must of course render the attraction between air and water more active ; but, *cæteris paribus*, hot air is a better solvent of water, than colder air. The cooling of hot atmospherical air is generally accompanied with a deposition of water, which, according to the quantity of water previously contained in the air, and the greater or less alteration of temperature, assumes the form of mists, or clouds, or rain : and on the other hand, the heating of air is attended with a dissipation of vapour, and an increase of transparency ; hence, as the sun rises, the mistiness of the night air, when no other circumstance inter-

\* It is impossible to annex more appropriate names to indefinite, or unsettled, ideas. Certain it is, that water will absorb a quantity of air, and that air absorbs a certain quantity of water ; and to those absorbing powers we give the name of *attraction* or *dissolving property* ; whether they are really owing to the attraction of cohesion, properly so called, or not.

ness, is gradually dissipated, and the atmosphere warms up; hence, in this country, the southerly and westerly winds, which drive the air from warmer latitudes, generally bring rains or mists; whereas the contrary effect is mostly produced by northerly easterly winds, which bring the air from colder regions. But the same change of temperature is always accompanied with the same dissipation or position of water in the atmosphere.

It has been fully established, by the result of a variety of experiments, that when water is converted to steam or vapour, it absorbs a quantity of heat, which is necessary to its elastic state; (for the steam water is elastic, viz. it may be compressed, or expanded, by the addition or diminution of pressure.) This quantity of heat is deposited when steam assumes the form of water.

If you moisten part of your hand, and then blow on it for the purpose of increasing the evaporation, you will feel that part of the hand sensibly cooled, viz. the water, in its assuming the form of steam, robs the hand of part of its heat. If you place your hand over the steam of boiling water, the hand is much warmed by the heat which the steam deposits upon it in its reassuming the form of water.

It is a common practice amongst sailors, to moisten one of their fingers by putting it into the mouth, and then to expose it above their head; by such means they can tell which way the wind

**blows;**

blows ; for that side of the finger which is exposed to the wind, feels colder than the rest, the evaporation on that side being promoted by the wind.

Besides the absorption of heat, the evaporation of water (as has been fully ascertained by the very able Professor Volta), is also attended with an absorption of electric fluid ; and on the other hand, the conversion of steam into water is attended with a deposition of electric fluid. The experiments, which prove those facts, will be found in the third part of these Elements, in the Section for Electricity.

It seems, therefore, that the formation of vapour, or clouds, or fogs, or rain, and such like phenomena, depends upon the concurrence of all the above-mentioned circumstances, and perhaps the formation and duration of each phenomenon in particular depends upon the various degrees of those different circumstances, which necessary degrees are by no means known.

The moisture of the atmosphere, or rather that quantity of water which is not in perfect solution with the air, but has not yet acquired the form of water, is measured by an instrument, called the *hygrometer*. The rain, or that quantity of water which falls from the clouds, or is deposited by the air in visible drops, is measured by means of another instrument, called the *pluvimeter* or *rain-*

gage. These instruments will be described at the end of this chapter.

The rain, which, as has been said above, consists of the water that has been exhaled from the surface of the terraqueous globe, either falls in very small particles of little gravity, in which case it is more properly called *dew*\*, or *mist* or *fog*; or else it falls in larger drops of various sizes, in which case it is properly called *rain*.

When the clouds are near, as is mostly the case in the winter season, or upon mountains, the drops of rain are small, not having time sufficient to join and to grow large. But when the clouds are very high, as is the case in the summer season, or in hot climates, the drops are much larger, and the rain very copious. A rain-gage, placed upon the surface of the earth, receives a greater quantity of rain in the same time, than a similar gage, which is situated higher up. A few feet difference of perpendicular altitude make a considerable difference †. The quantity of rain is expressed by inches and tenths; thus, if it be said that 20,3 inches of rain fell in one year in London, the meaning is, that if the surface of London had

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\* The *dew*, properly speaking, is that moisture which falls during the absence of the sun, and without the necessary presence of clouds.

† See the Phil. Transl. vol. 59th. art. 47. and vol. 67th.

been perfectly flat, and all the rain that fell upon it throughout that year, had remained upon it without evaporation, draining, or absorption, the depth of it would have amounted to 20,3 inches. Therefore, if a vessel open at top, and having straight up sides, be exposed to the atmosphere so as to receive the rain, and is so constructed as to prevent evaporation; the depth of water accumulated in that vessel, will shew the quantity of rain for the adjacent country, and the vessel itself is a rain-gage.

The quantity of rain which falls daily or annually in various parts of the world, has been, and is, frequently measured and registered; but it might be wished that such observations were instituted in a great many more places; for, considering how unequal and partial rains are, we must conclude, that the indication of a rain-gage will serve for no great extent of circumjacent country.

The rains on the vicinity of hills or mountains, or forests, are generally more copious than in other places. In several places, especially within the torrid zone, the rain is seldom seen. It has been asserted, as a real though singular fact, that it never rains in the kingdom of Peru; but that during part of the year the atmosphere over the whole country is obscured by thick fogs, called *garuas* \*.

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\* D'Ulloa's Voyage to South America, vol. II. p. 69.

A rain-gage is kept exposed over the apartments of the Royal Society in London, and its contents are noted frequently. It appears from that register, that a mean of the annual quantity of rain in London amounts to little more than 21 inches, but a considerable inequality exists between the quantities for the single years ; for sometimes, as in the year 1791, the quantity of rain is about 15 inches, and at other times, as in the year 1774, as also in 1779, the rain amounts to 26 inches and upwards.

At Upminster, in Essex, the annual average of rain is 19,14.

At Liverpool it is 37,43 inches.

At Townley, in the neighbourhood of the hills which divide Lancashire and Yorkshire, it is 41,516 inches.

At Lyndon, in Rutland, it is 24,6 inches.

At Dublin, in Ireland, it is about 22,25 inches.

At Paris, the annual average is 20,19 inches.

At Lisle, in France, it is 24 inches.

At Zuric, in Swisserland, it is 32,25 inches.

At Pisa, in Italy; it is 43,25 inches.

" The annual quantity of rain," as Dr. Dobson justly observes, " is a very uncertain test of the moisture or dryness of any particular season, " situation, or climate. There may be little or " even no rain, and yet the air be constantly damp " and foggy ; or there may be heavy rains, with  
" a com-

" a comparatively dry state of the atmosphere.  
 " The same depth of rain will likewise produce  
 " different effects on the air, according as it falls  
 " upon a flat or hilly country; for large quantities  
 " soon quit the hills, or high grounds, while  
 " smaller quantities have more lasting and pow-  
 " erful effects on a flat country. Much also de-  
 " pends upon the nature of the soil, whether clay  
 " or sand, whether firm or compact, or loose and  
 " spongy."

" Is not evaporation, therefore, a more accurate  
 " test of the moisture or dryness of the atmosphere,  
 " than the quantity of rain \*?"

But if it be considered that the evaporation from the surface of water only, is far different from the evaporation from the diversified surface of a country; the uncertainty of the latter method will appear equally great.

The hygrometer shews, that in general the moisture of the atmosphere is greater in low situations, than in more elevated places: but the most remarkable, and at the same time the most unaccountable, part of the subject is, that sometimes, (as has been observed by scientific persons) on mountains and other elevated situations, whilst the thermometer is stationary, and the hygrometer shews a considerable degree of actual and even increasing dryness, clouds are quickly formed, and often a copious rain succeeds; whereas,

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\* Phil. Trans. vol. 67th. p. 244.

at other times, a thick or clouded atmosphere quickly clears up, and that without any apparent cause.

. It seems as if the vapour of water changed its nature by being dispersed through the atmosphere. But we are certainly ignorant of that particular disposition in the atmosphere, which produces so great a change. We find, for instance, that clouds of immense extent, sometimes rise from the horizon; that instead of being driven by the existing wind, they actually change its direction; that other clouds are quickly formed. A great storm ensues; the rain is abundant; every thing acquires a considerable degree of moisture; yet an hour after, the serenity of the air is restored, and the natural process of evaporation becomes as vigorous as ever.

The quantity of evaporation from the land is, in general, much less than the rain which falls upon the same; whereas, from the surface of the sea, lakes and rivers, the evaporation exceeds the rain. The like difference does also exist between cold and warm climates. But the action of the winds, and the running of the superfluous rain-water from the land again into the sea, compensates the deficiencies, and keeps up a useful, necessary, and admirable circulation.

- We shall now endeavour to explain the principle and construction of hygrometers, as also of the rain-gage.

It has already been shewn, that in virtue of

the attraction of cohesion or capillary attraction, various substances are capable of absorbing moisture into their pores, or at least of holding it attached to their surface. If then the air contain a quantity of moisture, and a certain other dry substance has a greater attraction towards water than air has, then the moisture will quit the air, and will attach itself to that other substance; in consequence of which that other substance will be enlarged in its dimensions, or will be increased in weight. Now by measuring the diminished or increased dimensions, or the increased or diminished weight of that other substance, at different times, we acquire a knowledge of the quantity of water which has been deposited or absorbed by the air at those times. The instrument in which a substance fit for this purpose (called an *hygroscopic body*) is so situated as to shew a very small alteration of its length, or weight, is called an *hygroscope* or *hygrometer*.

A vast number of animal, vegetable, and mineral substances are susceptible of those alterations, but most of them are far from being fit for such an instrument. The twisted fibres of wild oats, sea-weed, salted strings, pieces of deal cut across the grain, a piece of cat-gut string, &c. are commonly used as indicators of moisture or dryness; but such substances are not fit for philosophical purposes; for they are unequal in their actions; their power of absorbing water increases or decreases, and sometimes entirely ceases in process of time; and

and very seldom two instruments, that are furnished with such substances, can be compared together.

Mr. De Luc, and Mr. De Saussure, both gentlemen of great knowledge and ingenuity, have examined a vast number of hygroscopic substances in a great variety of circumstances ; and, upon the whole, the latter of those gentlemen found reason to prefer a hair\* ; whilst the former prefers a very fine slip of whale-bone cut across the grain. Either of those substances is to be placed in a proper frame, which shews their elongations or contractions to a very minute quantity ; the instrument, or at least that part of it which holds the hygroscopic substance, is placed in water, which extends the substance to the utmost, and the point where the extremity of the substance reaches, is marked upon the instrument, and is called the *point of extreme moisture*. Then the instrument is removed from the water, and is placed into a large vessel almost full of unslacked quick-lime, wherein it is kept for a few days ; for as quick-lime has a considerable property of absorbing water copiously but slowly, the air in that vessel is very dry, and its degree of dryness is constantly the same during several months, notwithstanding the opening of the vessel, which must take place for putting in or taking out the hygrometers. By this means the *point of greatest*

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\* See his Work on Hygrometers, 2 vols. quarto.

*dryness* is obtained. Then the distance between this point and the point of greatest moisture, is divided into one hundred parts, and those parts are called the degrees of the hygrometer, or the degrees of moisture\*.

Those two sorts of hygrometers are tolerably uniform, and pretty quick in their action. Two or more of them are also comparable within a small difference. As upon the whole it appears that Mr. De Luc's hygrometer has some advantages over that of Mr. De Saussure's, I shall therefore describe it in Mr. De Luc's own words. See fig. 1. of Plate XV.

Those instruments may be made of various sizes, but they are mostly made of about twice the size of the figure.

" Their frame will sufficiently be known from  
 " the figure; therefore I shall confine myself to  
 " the description of some particulars. The *slip* of  
 " *whale-bone* is represented by *a b*, and at its end  
 " *a* is seen a sort of *pincers*, made only of a flattened  
 " bent wire, tapering in the part that holds the  
 " *slip*, and pressed by a *sliding ring*. The end *b*  
 " is fixed to a *moveable bar c*, which is moved by  
 " a screw for adjusting at first the *index*. The ends  
 " of the *slip* is hooked to a thin brass wire; to

\* From the point of greatest dryness to that of greatest moisture, a slip of whale-bone will be increased about one-eighth of its length.

" the other end of which is also hooked a very thin  
" silver gilt *lamina*, that has at that end *pincers* simi-  
" lar to those of the *slip*, and which is fixed by the  
" other end to the axis, by a pin in a proper  
" hole. The *spring*, *a*, by which the *slip* is stretch-  
" ed, is made of silver-gilt wire; it acts on the *slip*  
" as a weight of about 12 grains, and with this ad-  
" vantage over a *weight* (besides avoiding some  
" other inconveniences) that, in proportion as the  
" *slip* is weakened in its lengthening, by the pene-  
" tration of moisture, the *spring*, by unbending at  
" the same time, loses a part of its power. The  
" axis has very small pivots, the *shoulders* of which  
" are prevented from coming against the frame, by  
" the ends being confined, though freely, between  
" the flat bearings of the heads of two screws, the  
" front one of which is seen near *f*. The section  
" of that *axis*, of the size that belongs to a *slip* of  
" about 8 inches, is represented in fig. 2.; the  
" *slip* acts on the diameter *a a*, and the *spring* on the  
" smaller diameter *b b*\*.

After an assiduous and judicious use of hygrometers, made in the course of 20 years and upwards, Mr. De Luc formed some very useful deductions, which I shall subjoin in his own words.

" From those determinations in *bygrometry*,  
" some great points are already attained in *bygrology*,

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\* De Luc's Paper in the Phil. Trans. vol. 81st. part II.

" meteorology, and chemistry, of which I shall  
" only indicate the most important. 1st. In the  
" phænomenon of *dew*, the graft often begins to  
" be wet, when the *air* a little above it is still in a  
" middle state of *moisture*; and *extreme moisture* is  
" only certain in that *air*, when every solid exposed  
" to it is wet. 2dly. The *maximum of evaporation*,  
" in a close space, is far from identical with the  
" *maximum of moisture*; this depending considerably,  
" though with the constant existence of the other,  
" on the *temperature* common to the *space* and to  
" the water that evaporates. 3dly. The case of  
" *extreme moisture* existing in the open transparent  
" air, in the day, even in the time of *rain*, is ex-  
" tremely rare: I have observed it only once, the  
" temperature being  $39^{\circ}$ . 4thly. The *air* is *dryer* and  
" *dryer*, as we ascend in the atmosphere; so that in  
" the upper attainable regions, it is constantly very  
" dry, except in the *clouds*. This is a fact certified  
" by Mr. De Saussure's observations and mine.  
" 5thly. If the whole atmosphere passed from *ex-*  
" *treme dryness* to *extreme moisture*, the quantity of  
" water thus *evaporated* would not raise the *ba-*  
" *rometer* as much as half an inch. 6thly. Lastly,  
" in chemical operations on *airs*, the greatest  
" quantity of *evaporated water* that may be sup-  
" posed in them, at the common *temperature* of  
" the atmosphere, even if they were at *extreme*  
" *moisture*, is not so much as  $\frac{1}{10}$  part of their  
" mass. These two last very important propo-  
" sitions

" sitions have been demonstrated by Mr. De Saussure\*."

The mean height, for the whole year, of De Luc's hygrometer, exposed to the atmosphere in London, is about 79 degrees. It must, however, be observed, that hygrometers of every sort, even the above described one of Mr. De Luc, are very liable to be spoiled by long exposure; as dust, smoke, insects, &c. are apt to adhere to them; in which case their rate of going, or sensibility, is altered considerably. The proper action of De Luc's hygrometer may, in some measure, be preserved, by now and then placing the instrument in water, and gently cleaning the surface of the whale-bone slip, by means of an hair-pencil.—A steadier and more durable hygrometer is still a desideratum in natural philosophy.

Evaporation generates cold, and the quicker the evaporation takes place, the greater is the cold which is produced: therefore, if the bulb of a thermometer be just moistened, and then be exposed to the air, the mercury will descend lower when the evaporation is performed quicker, and *vice versa*. Upon this principle Mr. Leslie has constructed an instrument, which shews the quick-

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\* De Luc's Paper in the Phil. Transl. vol. 81st. part I. See also his Paper on *Evaporation* in the Phil. Transl. for the year 1792, part II. for farther illustration of the subject of Hygrometry.

ness of evaporation. The inventor calls it an hygrometer; but the quickness of evaporation does not indicate the moisture of the air in all cases\*.

The principle of the rain-gage has already been shewn in page 414. The rain-gage which is mostly used, is delineated in fig. 3. of Plate XV. It is an hollow vessel, of tined iron plates, japanned inside and out. The whole machine consists of three parts. A B C D is a cylindrical vessel, to the aperture of which the funnel F E x is nicely fitted. The upper part of the funnel has an edge of brass, which is perpendicular to the horizon, as is sufficiently indicated by the figure.

This gage, when exposed to the atmosphere, receives the rain which goes through the aperture x of the funnel, into the receiver A B C D; out of which it cannot evaporate, either out of the joint A D, which is very close, or out of the hole x, which, besides it being small, is partly occupied by the measuring rod. The measuring rod G H is fastened to an hollow float H, of japanned tin plates, which floats upon the water; and as the water fills the cylindrical vessel A D B C, so the float is raised, and part of the measuring rod comes out; and the divisions of the rod, which are out of the funnel,

\* See the description of this Hygrometer in Nicholson's Journal, vol. II. p. 461.

shew the quantity of water which is in the cylindrical vessel.

With respect to the divisions of the rod, it must be observed, that when the edge of the funnel and the cylindrical vessel are of the same diameter, then the divisions of the rod must be only inches and tenths, in order to shew the quantity of rain in inches and tenths ; but when the diameter of the cylindrical vessel is less than that of the edge F E, then the divisions must be longer, because an inch depth of rain, in an area of a certain diameter, will be more than an inch depth in an area smaller than that.—Those gages are made of various sizes, and the divisions of the measuring rod are made so as to indicate the inches of rain that would be accumulated in a cylindrical vessel whose diameter equalled the diameter of the brass edge F E.

A cross-bar with a socket, through which the measuring-rod passes, may be seen within the funnel. This serves to render the divisions of the measuring rod more legible. When no water is contained in the gage, and of course the float rests upon the bottom B C, then the o, or the beginning of the divisions of the rod is even with the upper part of the above-mentioned cross-bar.

## CHAPTER XIV.

**THE DESCRIPTION OF THE PRINCIPAL MACHINES,  
WHICH DEPEND UPON THE FOREGOING SUBJECTS  
OF FLUIDS.**

IN laying down the theory of fluids, both elastic and non-elastic, I have described as few machines, and those of as simple a construction, as the nature of the subject could admit of. This I have done, in the first place, for the purpose that the reader might not consider the knowledge of such subjects as unattainable, without the use of costly machines; and, secondly, that the connection of the theoretical reasoning might not be interrupted by the introduction of long and complicated descriptions.

But it is now, however, necessary to explain the construction and the use of those machines which have been contrived for the purpose either of measuring, or of elucidating, or, lastly, of applying to our purposes, the mechanical properties of fluids. And here we shall bestow our attention more on the principles than upon the variety of such machines.

The

*The Syphon, or Crane.*

A tube of glass, or metal, or other solid substance, open at both ends, and bent like the representation of fig. 4. Plate XV. is called a *syphon* or *crane*, and is commonly used for decanting liquors from one vessel into another. It is an indispensable requisite in the construction of this instrument, that the perpendicular altitude of the discharging leg A B, be greater than that of the sucking leg A C, (reckoning from A to the surface of the liquor, in which the leg A C is immersed). Then, when the aperture C is in the liquor, if, by applying the mouth at B, and sucking the air out of the syphon, its cavity be filled with the liquor ; on removing the mouth, the liquor will run out of the aperture B, and will continue to run as long as you continue to supply the vessel F with fluid, or as long as the surface of the fluid in the vessel F remains higher than the level of the aperture B.

The cause of this effect is the pressure of the atmosphere ; for when the syphon is full of liquor, the pressure of the atmosphere at B and C keeps the liquor up in the legs of the syphon ; and that pressure is partly counteracted by the perpendicular altitudes of the liquor in those legs ; but that counteraction is less at C than at B, because the perpendicular altitude A C is less than A B ; therefore

the

the atmosphere pressing at C, or (which is the same thing) on the surface of the liquor in the vessel F, more than at B, forces the liquor to run through the syphon.

It is evident that it is immaterial whether the diameters of the two legs be equal or not, provided the disparity be not so great as to introduce the obstruction from capillary attraction, &c.— Whether the legs be bent in various directions or not, is also immaterial ; provided the perpendicular altitude of the discharging leg be greater than that of the other.

It is also evident, from the theory, that the crane cannot act if the perpendicular altitude of its legs exceed 32 feet or thereabout. Nor can a syphon act in vacuo.

The best syphons that are at present in use for decanting liquors, have certain appendages which render their use more commodious. Fig. 5. of Plate XV. represents one of the best construction. It has a stop-cock D at the discharging aperture, and a small tube which runs along the outside of that leg, and communicates with the cavity of that leg just above the stop-cock. When the aperture C is situated within the liquor, the stop-cock is closed, and the mouth which sucks the air out, &c. is applied at E. Some of those syphons have no stop-cock, in which case the aperture B must be closed by the application of a finger, whilst the air is sucking out at E.

If

If several threads of cotton, a bunch of grafts, or some similar substance, be placed partly in a glass of water, and the other part (being the longest of the two) be left hanging out of the glass, as is shewn in fig. 15. of Plate XI.; the cotton or other substance will gradually absorb the water, in virtue of the capillary attraction; and when the whole is moistened sufficiently, the cotton, or other substance, will act as a syphon, and the water will keep dropping out of the external part of it.

A little machine, called *Tantalus's cup*, acts upon this principle, and its construction is as follows:

There is a hole quite through the bottom of a cup A. Fig. 6. Plate XV. and the longer leg of a syphon D E B G is cemented into the hole, so that the end D of the shorter leg D E may almost touch the bottom of the cavity of the cup. Now if water, or other liquor, be poured into the cup, the water will rise into the leg D E of the syphon, as it does in the cup, and will drive the air from that leg through the longer leg E G; but when the water has reached the upper part F of the syphon, it will not only run down and fill the other leg F G, but it will keep running out at G, until the cup is quite emptied. A little figure is sometimes placed over the syphon D F B, with the mouth open a little above F, which figure conceals the syphon, and represents Tantalus, who is deprived of the water, when the water has risen so . . .

*Description of the  
high within the cup, as nearly to reach his  
mouth.*

The reason, which principally induced me to describe the above-mentioned cup, is, that its action explains a curious natural phenomenon, viz. that of *intermitting or reciprocating springs*, called also *ebbing and flowing wells*.

There are certain springs or streams of water which issue out of rocks, and are rather copious for a certain time, then stop, and, after a certain period, come out again. The intermitting period is various, but sometimes it is very regular. The origin of those springs is, with great probability, owing to the following conformation, or to something similar to it.

A A, fig. 19. Plate XV. represents the perpendicular section of a hill, within which is a cavity B B, and from this cavity a natural channel runs in the direction B C D E, forming a natural syphon. The rain water, which descends from the upper part of the hill through various small crevices, G, G, G, gradually fills the cavity B B, as also the part B C of the channel, or shorter leg of the syphon ; but when the water gets above the level of C, then a stream will run through the channel, and out of it at E, until the cavity B B, as also the channel B C D E is quite emptied ; it being supposed that the draining of the water through the crevices G, G, G, cannot supply the cavity B B, so fast as it is drained by the channel B C D E.

Then

Then the flow of water at E stops, until so much water is again accumulated in the cavity BB, as to reach the level of C, at which time the stream reappears at E; and so on.

### *The Water Pump.*

There are several sorts of pumps for drawing water out of wells, springs, &c.; but they may be reduced to two sorts, viz. the common pump, generally called the *sucking pump*, and the *forcing pump*.

Fig. 15. Plate XV. represents a pump of the first sort. A B is a cylindrical pipe open at both ends, the lower of which is immersed in the water of the well, &c. Towards the lower part, as at C, there is a stopper with a hole and a valve, which opens upwards when any fluid pushes it from below, but is closed by any superincumbent force\*. In the upper part of the tube there is a piston

\* A valve is a piece of mechanism, that belongs almost to all sorts of hydraulic and pneumatic engines. Valves are made of different sorts, of which however the following are the principal.

Fig. 12. Plate XV. represents a stopple, with an oil silk valve; viz. a narrow slip of oil silk is stretched over the upper flat part of the stopple, so as to cover the central hole; and, being turned over the edge, is tied fast round

piston D, fastened to the handle or rod E, which generally is an iron rod. The piston consists of a piece of wood, nearly equal to the diameter of the cavity of the pump; but being covered over its cylindrical part with leather, it fits pretty tightly the cavity of the pump. In this piston there is a hole and another valve, like the one at C, which also opens upwards. The action of pumping consists in alternately moving the piston a certain way up and down, by which means the water ascends through the pump, and comes out of its upper aperture, or out of the spout F, when the upper part of the pump is furnished with such vessel and spout as is shewn in the figure. The action of this pump depends upon the gravity or pressure of the atmosphere; hence it could not possibly act in vacuo.

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round the stopple, as is indicated by the figure. In fig. 13, a flat and thick piece of leather is adapted to the upper flat part of a stopple, so as to cover the central hole. It has a little prolongation on one side, which is fastened to the stopple by means of a nail or screw, and a piece of lead is fastened to the upper part of the leather, in order to let it lay flat upon the hole. In fig. 14, the central hole is made a little conical at its upper part, and is shut up by a conical piece of metal, which rests upon it by its own gravity.

It is evident that a force from below will open any one of those valves; but a force from above will shut up the aperture more effectually.

When the piston is first drawn upwards, the air in C D is rarefied; hence the pressure of the atmosphere upon the surface of the water in the well forces the water to ascend a little way into the lower part of the pump; for instance, as high as G. Then the piston is pushed downwards, which contracting the distance C D, forces some air out of the valve D through the piston, but no air can get down through the valve at C; hence the water remains at G. After this, the piston is drawn upwards a second time, which rarefies the air in C D; in consequence of which the water ascends higher within the pump; thus, by degrees, the water gets above the valve C, and fills the space C D; and when this takes place, then, by lowering the piston, some water passes through the valve D, and remains above the piston; then, on lifting up the piston, that water is raised, and more water comes from the well through the valve C, &c.

It is hardly necessary to mention, that the height of the valve D, above the water of the well must never exceed 32 feet. Indeed, on account of the imperfections to which those mechanisms are subject, that height can seldom exceed 20 feet.

The force which is required to work a pump is as the height to which the water is raised, and as the square of the diameter of the pump at the place where the piston works; it being immaterial whether the rest of the pump be of the same diameter or not.

Pumps, in general, are worked not by applying the power immediately to the rod at E ; but the end of that rod is connected with the shorter arm of a lever, whilst the power is applied to the longer arm of the lever ; and since the longer arm of the lever is about five or six times as long as the other, therefore the power is by this means increased five or six times.—It has been found from repeated trials, that when the handle increases the power five times, when the diameter of the pump is four inches, and the water is to be raised 30 feet high ; the ordinary exertion of a labouring man can work it for a moderate continuance of time, and can discharge  $27\frac{1}{2}$  gallons of water (English wine measure) per minute.

Now, from the above-stated particulars, it will not be difficult to calculate the dimensions of a pump, which will discharge a given quantity of water at a certain height in a determinate time ; and what power will be required for the purpose.

The *forcing-pump*, fig. 16. Plate XV. raises the water above the valve H, in the same manner as the preceding pump ; but then, on lowering the piston, which in this pump is a solid piece without any valve or perforation, the water cannot get above it, but it is forced through the tube M N, and through the valve at P, into the vessel K K, which is called the *air-vessel* or *condensing-vessel*. Thus, by repeated strokes of the piston, the water is forced

to enter, and to accumulate into the vessel K K. driving the air out of it, through the pipe I G F, But when the water has been raised above the aperture I of the pipe, then the air, instead of being driven out, is condensed in the upper part of the air-vessel ; hence it begins to re-act upon the water by its elasticity ; in consequence of which the water is forced out of the pipe I H F, forming a jet, which rises higher, or goes farther and farther, according as the water is forced into the air-vessel with greater quickness, and the air in the upper part of the said vessel is contracted into a narrower space, by the rising of the water at O, within the vessel.—Some forcing-pumps have no air-vessel, but convey the water through a single uniform tube to the required height.

The jet, when there is an air-vessel, comes out without intermission ; for whilst the piston is ascending, the elasticity of the condensed air continues to act upon the water at O.

By means of this pump, the water may be raised to any height, provided there be working power adequate to the required effect, and the parts of the pump, and principally of the air-vessel, be sufficiently strong.

If to the extremity F of the discharging pipe, a flexible tube, either of leather, or of other pliable material, be adapted, so as to render the jet capable of being directed towards any particular place

at pleasure, then the mechanism becomes a fire-engine.

The principle of fire-engines, which are commonly used in this country, and elsewhere, for extinguishing fires, is nothing more than what has been already described. Their particular constructions, which have been diversified and improved by various able mechanics, differ only in a more or less compact disposition of parts; in having two or more forcing pumps; in having the levers capable of admitting several working-men, &c.

Water-pumps of every sort may be worked by other powers, besides the force of men. They may be worked by the wind, by horses, by a steam-engine, by a river, &c. A vast variety of mechanisms has been contrived for such purposes, which may be seen in almost all the works on mechanics, hydraulics, and other subjects allied to them; but those mechanisms must be contrived according to the particular circumstances of the situations, in which they are to be used.

The water-works at London-bridge consist of forcing-pumps, which are worked by the current of the river, viz. the current of the river turns a large vertical wheel, called the water-wheel, the axis of which has a number of cranks, which work as many levers, and at the ends of those levers are fastened the rods of the forcing-pumps. The

water

water is forced by them into a very strong condensing vessel of iron, and from this vessel various pipes convey and discharge the water to different parts of the town.

*Archimedes' Screw-Engine for raising Water.*

This simple and elegant contrivance of the great Archimedes, is shewn in fig. 18. Plate XV. It consists of a screw-like tube, open throughout, and fastened round an axis, which turns, together with the tube, round the pivots A, B.

This machine being placed with its lower part in water, must be inclined to the horizon at an angle of about 45 degrees; then by turning the handle M, the machine must be turned in the direction  $d a C$ ; viz. so that the lowest aperture of the tube may go against the water; and by this means the water will be raised from A, and will be discharged by the upper aperture i, into a proper vessel, S, which must be placed under it, to receive the water, and to convey it wherever it may be required.

In order to understand the action of this machine it must be considered, 1st, That every successive part or point in the length of the tube, is farther and farther from the lowest part of the machine, or is nearer and nearer to the aperture i. 2dly, That the small quantity of water which is in the inferior part  $d$ , of any convolution of the tube, cannot (in virtue of its gravity) remain affixed

to that identical part of the tube, when, by the turning of the machine, that part comes to the higher situation *a*; but it must pass on to the next part of the tube, then to the next to that, and so on. But those successive parts come nearer and nearer to the aperture *i*; therefore that quantity of water must pass gradually from the lowest to the highest part of the tube, until it comes out itself of the aperture *i*.

What has been said of this quantity of water, may evidently be said of the next, and, in short, of all the water which is raised by the machine.

Instead of the handle *M*, sometimes a pretty large wheel is affixed to the lowest part of the machine, which, on account of the inclination, will be partly immersed in water; in consequence of which, the machine will be turned by the water itself; supposing that water to be a river, or running stream.

Sometimes, instead of one, two tubes are fixed round the axis of this machine; but its construction has been altered various ways, which need not be particularly described, since the principle itself of the machine remains unaltered.

Such machines are useful for raising water to a great height; for when the elevation is considerable, the machine, on account of its inclined position must be long, heavy, and liable to be bent, in which case its action would cease.

### The Rope Machine for raising Water.

If a vertical grooved wheel, fixed to a frame, be situated within the water at the bottom of a well, and another similar wheel, having a handle annexed to its axis, be situated in another frame at the upper part of the well; also an endless rope (viz. a rope whose two extremities are spliced into each other), be passed round both wheels; then, by turning the handle, the wheels and the rope will be caused to move, viz. the rope will ascend up out of the well, and descend on the other, passing successively through the water of the well; but the descending part will carry up a quantity of water adhering to it in its course, and this water differs in quantity, according to the size of the rope, the depth of the well, &c. the quickness of the motion; viz. while a rope will, in a less deep well and spliced groove, a greater quantity of water will be raised, than where a

In order to intercept the water at the top of the well, the upper wheel is inclosed in a small cage box, in the bottom of which there are two holes through which the descending end passes, so that of the rope pass. To this cage are attached short tubes, which prevent the end of the rope which falls to the bottom of the well from touching the bottom, for

~~to~~ ~~the~~ ~~bottom~~ ~~of~~ ~~the~~ ~~well~~ ~~have~~  
been

the broad sides of the box there are two holes for the axis of the wheel. The 11th and 10th figures of Plate XV. exhibit a section and a front view of a machine of this sort, which was put up in the year 1782, on the castle hill at Windsor, where the depth of the well is 95 feet\*.

The same letters refer to the like parts in both figures.

The wheel H at the bottom of the well is of *Lignum vite*, one foot in diameter. Its axis is of steel, and turns with its extremities in sockets of bell-metal.

The frame II is of iron.

The wheel EE at the top of the well is of iron; but its rim, with the grove which receives the rope, is of lead. The diameter of this wheel is three feet.

The axis dd is of steel, and its extremities turn in bell-metal sockets, which are fixed in two upright posts AA, that support the machine. T is the handle affixed to the axis, which handle describes a circle of 28 inches in diameter; bb is the wooden box, lined with lead, which incloses the wheel E. FF are the holes at the bottom of the box through which the rope passes. Their diameter is about two inches.

\* A similar machine was also placed on the round tower of Windsor castle, which draws the water from the depth of 178 feet.

On the same axis *dd*, another wheel *CC*, of about four feet in diameter, is fixed. This wheel is of wood, loaded on the edge with lead, and it serves as a fly to facilitate the motion.

The rope is of horse-hair, and measures half an inch in diameter.

With this identical machine, several experiments were tried, the result of which is as follows:

When the machine was worked slowly, viz. so as to make about 30 revolutions of the handle in one minute, then very little water came up adhering to the rope; and of this water a very small portion was separated from the rope within the box, so as to come out of the spout *Z*, in the side of the box.

When the revolutions of the handle were about 50 in a minute; then a considerable quantity of water came up adhering to the rope; and on turning the wheel *EE* round, the greatest part of that water, having acquired a considerable velocity, flew off in a tangent from the rope, and formed a jet within the box. This water falling to the bottom of the box, came out of the spout *Z*.

It was found that the utmost exertion of an ordinary working man, could not make more than 60 revolutions of the handle in a minute; in which case the rope moved at the rate of about 16 feet per second. With this velocity the quantity of water that came out of the spout *Z*, was about six gallons per minute; but it would have

been impossible for the man to have worked at that rate for more than three or four minutes.

This machine may evidently be placed afloat, viz. so as to convey the water from one place to another, which is not quite perpendicular over the former. The same construction and almost the same expence will adapt the machine to wells of different depths, though the effects will not be always the same.

More than one rope, or a broad band instead of a rope, might be adapted to this machine, for which purpose the wheels must have more shape, or a broad, groove, &c.

The greatest disadvantage of this machine is, that the rope does not last long. Its being always wet destroys it very soon.—In putting on the rope, care must be had to soak it well in water before it be spliced; otherwise it will either be too tight, or it will break.—A hair rope has been found to last longer than one of hemp.

### *The Mechanical Paradox.*

The effect which arises from that curious property of non-elastic fluids, viz. from their pressing upon equal bottoms, according to their perpendicular altitudes, without any regard to their quantities, has been commonly called the *hydrostatical paradox*, and various machines, more or less complicated, have been constructed for the purpose of rendering it strikingly

strikingly evident; but after the theoretical explanation which has been given of that property, it seems useless to employ more pages on the description of such machines. I shall, however, add one of the least complicated construction. This is represented in fig. 7. Plate XV. It is commonly called the *hydostatical bellows*.

It consists of two thick oval boards, each about 16 inches broad and 18 inches long, joined by means of leather, to open and shut like common bellows, excepting that they move parallel to each other. A pipe B, about 3 feet high, is fixed into the bellows at e.

Let some water be poured into the pipe at e, which will run into the bellows, and separate the boards a little. Lay three weights b, c, d, each weighing 100 pounds, upon the upper board; then pour more water into the pipe B, which will run into the bellows, and will raise the board with all the weights upon it; and if the pipe be kept full, until the weights are raised as high as the leather which covers the bellows will allow them, the water will remain in the pipe, and support all the weights, even though it should weigh no more than a quarter of a pound, and they 300 pounds; nor will all their force be able to cause them to descend and force the water out at the top of the pipe.

A man may stand upon the upper board, instead of the weights, and he may raise himself by pouring water into the pipe B; which will appear very wonderful

*Description of the*

wonderful to unskilled persons; but the wonder will vanish, if it be considered that if the man raises himself one tenth part of an inch, the water must descend down almost the whole length of the pipe; so that the small quantity of water in the pipe can balance the weight of the man; because their velocities, or the spaces they must move through, are inversely as their weights; which renders their momentums equal.

I shall not describe the various sorts of mills, or of other hydraulic engines, on three accounts principally, viz. first because those machines, though very useful, do not point out any new property of fluids, besides what have been already explained; secondly, because the descriptions of those engines may be found in a variety of books, such as dictionaries of arts and sciences, transactions of learned societies, treatises on mechanics, on hydrostatics, &c. and 3dly, because, by the insertion of those descriptions, this work would be swelled up to an enormous size.—The following machine is not very commonly known.

*The Machine for Blowing, by means of a Fall of Water.*

Wherever there is the conveniency of a fall of water, which is frequently the case in the vicinity of hills, mountains, &c, there a machine for blowing the fire of a furnace may be easily constructed;

and

and it will prove both useful and lasting, almost without any farther expence than that which attends the original construction.

The dimensions of such machines must be suited to the circumstances of the situation, size of the furnace, &c. but those particulars may be easily derived from the general principles of the construction, which I shall give in the words of Professor Venturi, the gentleman who has given the best and most recent explanation of those principles.

" Let BCDE, fig. 17. Plate XV. represent " a pipe, through which the water of a canal AB, " falls into the lower receiver MN. The sides of " the tube have openings all round, through which " the air freely enters to supply what the water car- " ries down in its fall. This mixture of water and " air proceeds to strike a mass of stone Q; whence " rebounding through the whole width of the re- " ceiver MN, the water separates from the air, " and falls to the bottom at XZ, whence it is dis- " charged into the lower channel or drain, by one " or more openings T, V. The air, being less " heavy than the water, occupies the upper part " of the receiver, whence, being urged through " the upper pipe O, it is conveyed to the " forge.

" I formed one of these artificial blowing engines " of a small size. The pipe BD was two inches " in diameter, and four feet in height. When the

" water accurately filled the section B C, and all  
 " the lateral openings of the pipe B D E C were  
 " closed, the pipe O no longer afforded any  
 " wind." (See the note in page 180 of this  
 volume.)

" It is, therefore, evident, that in the open pipes  
 " the whole of the wind comes from the at-  
 " mosphere, and no portion is afforded by the de-  
 " composition of water. Water cannot be decom-  
 " posed and transformed into gas, by the sim-  
 " ple agitation and mechanical percussion of its  
 " parts. The opinions of Fabri and Dietrich  
 " have no foundation in nature, and are contrary  
 " to experiment.

" It remains, therefore, to determine the cir-  
 " cumstances proper to drive into the receiver  
 " M N, the greatest quantity of air, and to mea-  
 " sure that quantity. The circumstances which  
 " favour the most abundant production of wind,  
 " are the following :

" 1. In order to obtain the greatest effect from  
 " the acceleration of gravity, it is necessary that  
 " the water should begin to fall at B C, with the  
 " least possible velocity; and that the height of  
 " the water F B should be no more than is necel-  
 " sary to fill the section B C. I suppose the ver-  
 " tical velocity of this section to be produced by an  
 " height or head equal to B C.

" 2. We do not yet know, by direct experi-  
 " ment, the distance to which the lateral commu-

" situation of motion between water and air can extend itself; but we may admit, with confidence, " that it can take place in a section double that of " the original section with which the water enters " the pipe. Let us suppose the section of the pipe " B D E C, to be double the section of the water " at B C; and in order that the stream of fluid " may extend and divide itself through the whole " double section of the pipe, some bars, or a grate, " are placed in B C, to distribute and scatter the " water through the whole internal cavity of the " pipe.

" 3. Since the air is required to move in the " pipe O, with a certain velocity, it must be " compressed in the receiver. This compression " will be proportioned to the sum of the accelerations, which shall have been destroyed in the " inferior part K D of the pipe. Taking K D " equal to one foot and a half, we shall have a " pressure sufficient to give the requisite velocity " in the pipe O. The sides of the portion K D, as " well as those of the receiver M N, must be exactly closed in every part.

" 4. The lateral openings in the remaining " part of the pipe B K, may be so disposed " and multiplied, particularly at the upper part, " that the air may have free access within the " tube. I will suppose them to be such, that " one-tenth part of a foot height of water " might be sufficient to give the necessary velocity

" locity to the air at its introduction through the  
" apertures. (1)

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(1) " All these conditions being attended to, and sup-  
" posing the pipe BD to be cylindrical, it is required to de-  
" termine the quantity of air which passes in a given time  
" through the circular section KL. Let us take, in feet,  
" KD = 1,5; BC = BF =  $a$ ; BD =  $b$ . By the  
" common theory of falling bodies, the velocity in KL will  
" be  $7,76 \sqrt{a + b - 1,4}$ ; the circular section KL  
" =  $0,785 a^2$ . Admitting the air in KL to have ac-  
" quired the same velocity as the water, the quantity of the  
" mixture of the water and air, which passes in a second,  
" through KL, is =  $6,1 a^2 \sqrt{a + b - 1,4}$ . We must  
" deduct from the quantity ( $a + b - 1,4$ ) that height  
" which answers to the velocity the water must lose by that  
" portion of velocity which it communicates to the new air  
" laterally and constantly introduced; but this quantity is  
" so small, that it may be neglected in the calculation.  
" The water which passes in the same time of one second  
" through BC, is =  $0,4 a^2 \sqrt{a + 0,1}$ . Consequently,  
" the quantity of air which passes in one second through  
" KL, will be =  $6,1 a^2 \sqrt{a + b - 1,4} - 0,4 a^2 \sqrt{a + 0,1}$ ;  
" taking the air itself, even in its ordinary state of com-  
" pression, under the weight of the atmosphere. It will be  
" proper, in practical applications, to deduct one-fourth  
" from this quantity; 1st, on account of the shocks which  
" the scattered water sustains against the interior part of the  
" tube, which deprive it of part of its motion; and, 2dly,  
" because it must happen that the air in LK will not, in  
" all its parts, have acquired the same velocity as the  
" water."

" If

" If the pipe O do not discharge the whole quantity of air afforded by the fall, the water will descend at X Z ; the point K will rise in the pipe, the afflux of air will diminish, and part of the wind will issue out of the lower lateral apertures of the pipe B K \*."

### *The Anemometer, or Wind-gage.*

The direction and the strength are the two particulars which may be required to be ascertained with respect to the wind.

The methods of determining the actual direction, by means of wind-vanes, or of the motion of clouds, &c. are too common and too obvious, to need any particular description ; but for the purpose of measuring the force of the wind, several instruments have been contrived ; such as a board fastened to the rod of a pendulum, which shews the strength of the wind by the angle to which the pendulum is caused to deviate from the perpendicular ; such also as a small windmill, which, by the number of revolutions that are performed in a given time, gives an estimate of the force of the wind, &c. but amongst all those instruments, the most portable, less equivocal, and less complicated,

\* Venturi's Experimental Enquiry on the lateral communication of motion in fluids. Prop. VIII.

wind-gage, is one which was contrived by Dr. James Lind of Windsor: this is delineated in fig. 8. Plate XV. which is about one-half of the real, or more usual, size of such instruments.—*Philosophical Transactions*, vol. 65, p. 353.

“ This simple instrument consists of two glass tubes, A B, C D, of five or six inches in length.\* Their bores, which are so much the better always for being equal, are each about  $\frac{4}{10}$  ths of an inch in diameter. They are connected together like a syphon, by a small bent glass tube a b, the bore of which is  $\frac{1}{10}$  th of an inch in diameter. On the upper end of the leg A B, there is a tube of latten brass, which is kneed or bent perpendicularly outwards, and has its mouth open towards F. On the other leg C D is a cover, with a round hole G in the upper part of it,  $\frac{2}{10}$  ths of an inch in diameter. This cover, and the kneed tube are connected together by a slip of brass c d, which not only gives strength to the whole instrument, but also serves to hold the scale H I. The kneed tube and cover are fixed on with hard cement, or sealing-wax. To the same tube is soldered a piece of brass e, with a round hole in it, to receive the steel spindle K L, and at f there is just such another piece of brass soldered to the brass hoop g h, which surrounds both legs of the instrument. There is a small

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\* “ They ought to be longer, as in several cases the abovementioned length has been found insufficient.”

shoulder on the spindle at *f*, upon which the instrument rests, and a small nut at *i*, to prevent it from being blown off the spindle by the wind. The whole instrument is easily turned round upon the spindle by the wind, so as always to present the mouth of the kneed tube towards it. The lower end of the spindle has a screw on it; by which it may be screwed into the top of a post, or a stand made on purpose. It also has a hole at *L*, to admit a small lever for screwing it into wood with more readiness and facility. A thin plate of brass, *k*, is soldered to the kneed tube about half an inch above the round hole *G*, so as to prevent rain from falling into it. There is likewise a crooked tube *A B*, fig. 9. to be put on occasionally upon the mouth of the kneed tube *F*, in order to prevent rain from being blown into the mouth of the wind-gage, when it is left out all night, or exposed in the time of rain. The force or *momentum* of the wind may be ascertained by the assistance of this instrument, by filling the tubes half-full of water, and pushing the scale a little up or down, till the *o* of the scale, when the instrument is held up perpendicularly, be on a line with the surface of the water, in both legs of the wind-gage. The instrument being thus adjusted, hold it up perpendicularly, and turning the mouth of the kneed tube towards the wind, observe how much the water is depressed by it in one leg, and how much it is raised in the other. The sum of the two is the height of a column of water which the wind is capable

pable of sustaining at that time; and every body that is opposed to that wind, will be pressed upon by a force equal to the weight of a column of water, having its base equal to the surface that is exposed, and its height equal to the altitude of the column of water sustained by the wind in the wind-gage. Hence the force of the wind upon any body, where the surface opposed to it is known, may be easily found, and a ready comparison may be made betwixt the strength of one gale of wind and that of another, by knowing the heights of the columns of water, which the different winds were capable of sustaining. The heights of the columns in each leg will be equal, provided the legs are of equal bores; otherwise the heights must be calculated accordingly.

" The force of the wind may likewise be measured with this instrument, by filling it until the water runs out at the hole G. For if we then hold it up to the wind as before, a quantity of water will be blown out; and, if both legs of the instrument are of the same bore, the height of the column sustained will be equal to double the column of water in either leg, or the sum of what is wanting in both legs. But if the legs be of unequal bores, then the heights must be calculated accordingly.

" On land this instrument may be left out exposed all night, &c.; but at sea it must always be held up by the hand in a perpendicular position, whether

whether it be used when only half-full of water, or when quite full; which last will be frequently found to be the only practicable method during the night.

"The use of the small tube of communication  $ab$ , fig. 8. is to check the undulation of the water, so that the height of it may be read off from the scale with ease and certainty. But it is particularly designed to prevent the water from being thrown up to a much greater or less altitude than that which the wind can sustain.

"The height of the column of water sustained in the wind-gage being given, the force of the wind upon a foot square is easily had by the following table, and consequently on any known surface."

*Description of the*

<i>Height of the water in the gage.</i>	<i>Force of the wind on one foot square in pounds avoirdupoise.</i>	<i>Common designations of such winds.</i>
Inches 12 — —	62,500	
11 — —	57,293	
10 — —	52,083	most violent hur-
9 — —	46,875	ricane.
8 — —	41,667	very great hurricane.
7 — —	36,548	great hurricane.
6 — —	31,750	hurricane.
5 — —	26,041	very great storm.
4 — —	20,833	great storm.
3 — —	15,625	storm.
2 — —	10,416	very high wind.
1 — —	5,208	high wind.
0,5 — —	2,604	brisk gale.
0,1 — —	0,521	fresh breeze.
0,05 — —	0,260	pleasant wind.
0,025 — —	0,030	a gentle wind.

When the height of the water is not exactly mentioned in the table, then that height may be separated into such parts as are mentioned in the table, and the sum of the forces answering to such parts will be the force of the wind correspondent to the height in question ; thus, if the height of the water be 4,6 inches ; then this height is equal to 4, plus

plus 0,5, plus 0,1, which parts are all in the table; therefore

	lbs.
4 inches	20,833
0,5 —	2,604
0,1 —	<u>0,521</u>

The sum is 23,958, which expresses the force of the wind when the height of the water in the gage is 4,6 inches.

Any alteration that can usually take place in the temperature of the water, makes no sensible difference in this instrument.

In frosty weather this gage cannot be used with common water. At that time some other liquor must be used, which is not so subject to freeze; and, upon the whole, a saturated solution of common salt in water is the most eligible: but in that case (since the specific gravity of a saturated solution of salt is to that of pure water as 1,244 to 1) the forces which are stated in the preceding table must be multiplied by 1,244. Thus, if in the preceding example the saturated solution of salt had been used instead of water only, the force of the wind on a square foot, would have been 29,8 pounds \*.

The

\* When salt-water is used, the force of the wind, which is stated in the table, must be increased in the proportion of

*The Barometer.*

The construction of the barometer has been so often varied at different times, and by different ingenious persons, that a description of all its shapes and varieties would be endless; but it would at the same time be useless, since few of those various constructions are really sufficiently useful, either for the common purpose of indicating the variations of the gravity of the atmosphere, or for the purpose of measuring altitudes.

As the usual perpendicular movement of the mercury in the barometer, upon the whole, hardly amounts to two inches and a half, therefore the principal object of various ingenious persons has been to extend the scale, so that very small variations might be rendered apparent.

One of the methods by which this object has been accomplished, is represented in fig. 8. of Plate XVI.

A B is a glass tube about 5 or 6 feet long, open at its lower end, and having an enlargement C D at

the specific gravity of salt-water to that of common water; thus, using the preceding example, we must say, as 1 : 1,244 :: 23,958 to a fourth proportional, which must be found by multiplying the second term by the third, and then dividing the product by the first term; but, the first term being unity, we need only multiply 23,958 by 1,244.

the

the height of between 28 and 31 inches above its lower extremity. This tube is filled with mercury as high as about CD, viz. the middle of the enlargement of its cavity; and the upper part of it, viz. from the surface CD of the mercury, to a certain place E, in the upper part GB of the tube, is filled with tinged spirit of wine; the remaining space EB being a vacuum. F is a basin containing quicksilver, wherein the lower end of the tube is immersed.

When the mercury rises in the barometer; for instance, one inch in the enlargement, CD, it is evident that a certain quantity of spirit of wine must be forced by it into the part GB, which will fill much more than one inch length of the tube GB, first because one inch altitude of the cavity CD contains spirit of wine enough to fill up some inches length of the tube GB; and 2dly, because one inch perpendicular altitude of quicksilver is equivalent to several inches perpendicular altitude of spirit of wine. By this means a small variation of the altitude of the mercury in CD, is indicated by a much more apparent variation of the altitude of the spirit of wine in GB.

Barometers, containing mercury and spirits, or mercury and water, or mercury and some other liquor, have also been made of several parallel tubes connected together in a zigzag way; but I need not detain my reader by a particular description of such barometers, since they are all much more imperfect

perfect than the simple straight mercurial barometer. Their imperfections principally arise from the expansion and contraction of the other fluid besides the mercury, and from the vapour which being extricated from that other fluid, and occupying the upper part of the tube, counteracts in great measure the pressure of the atmosphere.

The elongation of the scale, or of the apparent motion of the barometer, has also been accomplished by inclining part of the mercurial barometer. Thus, in fig. 9. Plate XVI. the tube is straight from the basin B, to the altitude A, viz. about 28 inches, but the rest, A C, is inclined to the horizon.

Now, as the ordinary perpendicular motion of the quicksilver amounts to about three inches, which is equal to AD; therefore, when it moves not perpendicularly from A to D, but obliquely through A C, it must run all the way from A to C, in order to attain three inches of perpendicular altitude; so that if the part A C be 12 inches long, viz. four times as long as the part A D, then, whilst the mercury in a straight barometer rises one inch, in this slant barometer, it will run along four inches length of the part A C; and of course the small alterations of the pressure of the atmosphere are thereby rendered more apparent. Yet this slant barometer is by no means so accurate as a straight one; and the causes of its inaccuracy principally, are the obliquity of the surface of the mercury in the

the part A C, the difficulty of obtaining, or of knowing, when the part A C is perfectly straight, and the want of freedom in the motion of the quicksilver, which arises from its attraction towards the glass, and which increases with the increase of the obliquity of the part A C.

Barometers are also made to move circular indexes; they have likewise been made with an horizontal elongation at the lower part of the tube; always for the purpose of extending the scale. But all those constructions are attended with considerable imperfections; so that, upon the whole, the straight mercurial barometer is the best. Upon such a barometer for common purposes, the altitude may be commodiously read off to the exactness of one-hundredth part of an inch; and on those which are made for measuring altitudes, as mountains, &c. it may generally be read off within the 500th part of an inch.

I need not describe the ornamental part of the common barometers, which is varied by the fancy of every maker; but a complete one is shewn by fig. 14. Plate XVI.; two things, however, deserve to be mentioned, viz. the more usual construction of the lower part, or of the cistern; and the nature of the nonius, which (in the best construction) is affixed to the index for the purpose of indicating the small parts of an inch.

The lower part of the tube is sometimes bent and enlarged, as is shewn by fig. 10. of Plate XVI.

in which construction, when the barometer is to be removed from one place to another, the instrument is turned gently upside down, and the mercury filling the whole tube, comes not higher than the curvature A ; but when the barometer is set straight up against a wall in the usual way, then the quicksilver descending a little way from the closed upper end of the tube, fills the part A B, and rises a little way within the enlarged part B ; which in fact is the cistern of the barometer. Sometimes the barometers are made with an open cistern, in which case they act well, but are not portable, unless they be carried straight up, and very gently, from one place to another.

The most portable barometers of the common sort, have a little bag made of a piece of bladder, tied round their lower extremity. This bag and tube are filled with mercury, and no part of that mercury is exposed to the atmosphere; but the atmosphere presses upon the outside of the bag, which answers the same purpose. To those barometers a screw S, fig. 13. Plate XVI. is affixed to the frame, which, when the barometer is to be carried from place to place, is screwed upwards by applying the hand to the milled head T, by which means the pressure of the screw against the bag, pushes the mercury into the tube, fills up the whole length of the tube, and renders the instrument quite portable.

On reflection it will appear, that, according to  
the

the above-mentioned construction of cisterns, when the mercury rises in the tube, it must fall in the cistern; in consequence of which the altitude of the mercury should always be reckoned from the surface of the mercury in the cistern; this, however, excepting in barometers for measuring altitudes, is in general not taken notice of; since the difference is not great.

The principle of what is commonly, though improperly, called *nonius*, may be better explained by means of an example. This curious contrivance is of great use; and in fact it has been applied to a great variety of philosophical, and principally of astronomical, instruments \*.

Suppose that a scale, as A B, fig. 11. Plate XVI. is divided in inches only, and that the parts of an inch (for instance, the quarters) be required to be measured by means of a nonius: C D is the nonius, viz. a little scale, moveable over, or along, the side of the scale A B. The construction of this nonius is such, that the distance CD, which is equal to three inches, is divided into four equal parts;

\* "This method was published by Peter Vernier (a gentleman of Franche Comté) at Brussels, in the year 1631; and which, by some strange fatality, is most unjustly, although commonly, called by the name of *Nonius*; for *Nonius's* method is not only very different from that of *Vernier*, but much less convenient." Robertson's Navigation, B. V. §. 219.

whereas, on the scale, the same length is divided into three equal parts; so that the divisions of the nonius are to those of the scale as 4 to 3. Therefore the parts, or divisions, of the nonius are shorter than the divisions of the scale, viz. each part of the nonius must be equal to three-quarters of each division of the scale; hence the first division of the nonius, which lies between 0 and  $\frac{1}{3}$ , is one-quarter of an inch shorter than the next division of the scale; the second division of the nonius is half an inch distant from the next division of the scale; and the third division of the nonius is three-quarters of an inch distant from the next division (meaning always towards the right-hand) of the scale.

Now, when I am to measure the distance E F, by the application of the scale, I find it equal to four inches; but if I want to measure the distance E G, the scale will shew that it is more than four inches, but not how much more; now, in order to find how much more than four inches that distance EG is, I move the nonius forward until its edge D coincides with G. (Here the distance EG is not placed close to the scale and nonius, only to avoid confusion) and in that case, I find that the third division of the nonius coincides with one of the divisions of the scale; but that division of the nonius, as has been shewn above, was three quarters of an inch distant from the next division of the scale; therefore the nonius has now been advanced three quarters of an inch, as is shewn by fig. 12. and

of course the length EG is four inches and three-quarters.

What has been said of this nonius may be easily applied to explain the principle of every other nonius; viz. as by this nonius we have the quarters of an inch, because the same space of three inches is divided into three equal parts on the scale, and into four equal parts on the nonius; so we may have the tenths of an inch if the same space of 9 inches be divided into 10 equal parts on the nonius; so also we may have the hundredths of an inch, if the same space, which is divided into 9-tenths of an inch on the scale be divided into 10 equal parts on the nonius; and so forth.

The barometers for measuring mountains, or altitudes in general, must be made with much greater accuracy than those of the common sort; their scale must be longer; the mercury in the cistern must be raised by means of a screw always to the same mark, in order that the divisions of the scale may indicate the real altitudes of the surface of the mercury in the tube above that of the mercury in the cistern. They also must be furnished with a stand capable of supporting them in a perpendicular situation; for otherwise they cannot be suspended straight up on the sides of mountains; and great care must be had to render such instruments as portable and as secure as possible.

Various contrivances have been made and executed for the attainment of such objects. The latest,

and

and perhaps the best, but by no means the simplest, was made by Mr. Haas; I shall, however, briefly describe the construction of the portable barometers contrived and constructed by the late very ingenious philosophical instrument-maker, Mr. Jesse Ramsden, which have been used by various philosophical gentlemen, and especially by Colonel Roy in his numerous measurements. Fig. 20. and 21. of Plate XVI. exhibit a barometer of this construction, both in the situation proper for observation, and packed up.

" The principal parts of this instrument are a  
" simple straight tube, fixed into a wooden cistern  
" A, which, for the convenience of carrying, is  
" shut with an ivory screw B, and that being re-  
" moved, is open when in use. Fronting this  
" aperture is distinctly seen the coincidence of the  
" gage-mark, with a line on the rod of an ivory  
" float, swimming on the surface of the quicksilver,  
" which is raised or depressed by a brass screw C at  
" the bottom of the cistern. From this, as a fixed  
" point, the height of the column is readily mea-  
" sured on the scale D attached to the frame, al-  
" ways to  $\frac{1}{30}$  part of an inch, by means of a no-  
" nius E, moved with rack-work. A thermo-  
" meter F is placed near the cistern, whose ball  
" heretofore was usually inclosed within the wood-  
" work, a defect that hath been since remedied.  
" The three-legged stand, supporting the instru-  
" ment when in use, serves as a case for it when  
" inverted

" inverted and carried from place to place, fig. 21.  
" Two of these barometers, after the quicksilver  
" in them hath been carefully boiled, being suffered  
" to remain long enough in the same situation, to  
" acquire the same temperature, usually agree in  
" height, or rarely differ from each other more  
" than a few thousandth parts of an inch\*."

### *The Air-Pump.*

The *air-pump* is an instrument which serves to draw, or pump, the air out of any vessel which is properly adapted to it. This noble engine is one of the principal instruments which have, since the middle of the 17th century, contributed to the rapid advancement of natural philosophy, by affording the means not only of verifying what had been advanced and conjectured by several learned persons concerning the atmosphere ; but likewise of trying a great many experiments, and of ascertaining a vast number of new and interesting facts.

The original principle or construction of the air-pump is similar to that of the common water-pump which we have already described ; excepting that the parts of the air-pump must be executed with

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\* Philosophical Transactions, vol. 67. p. 658.

very great accuracy, for the purpose of intercepting the passage of the air, where that is not wanted, and which, on account of the pressure of the atmosphere and the subtlety of the air, cannot be well intercepted, without the utmost mechanical accuracy.

The first construction of the air-pump was very imperfect, but a variety of improvements gradually removed its imperfections, and multiplied its varieties, so that at present there are various sorts of air-pumps in use, which are more or less complicated, more or less effectual in exhausting, and more or less expensive. The history of most of its improvements and shapes, makes a very entertaining article in various books, and especially in the *Encyclopædia Britannica*, under the article *Pneumatics*; but several of those improvements need not be noticed at present, since they have been superseded by better contrivances. The description of the particular constructions, at least of the most useful, may be found in the above-mentioned article, or in other works that are mentioned in the note. We shall only describe the principle of the simplest pump which is now in use, for the purpose of giving the student a clear idea of the principal parts of that exhausting engine, and shall then subjoin the description of an improved one which was lately contrived and executed by Mr. Haas, especially

as that construction has not, as far as I know, been described in any other publication\*.

Fig.

\* The air-pump was first invented by Otto Guericke, a gentleman of Magdeburgh in Germany, about the year 1654. (*Schottus. Mech. Hydraulico-Pneum.*) Soon after, Guericke's contrivance was imitated and greatly improved, in England, by the celebrated and indefatigable Mr. Boyle (see his works), who was assisted by several eminent persons, and especially by Dr. Hook, a gentleman of a most inventive mechanical genius. But the want of skill in the then existing workmen, and the deficiency of several articles, still rendered the air-pump a very imperfect instrument, until Mr. Hawkesbee produced an improved and elegant engine of that sort, which has been copied by many artists here and elsewhere, and is even at present in use amongst philosophers. (See the description of it in Dr. Desagulier's Philosophical Works.) Another pump, somewhat different, was also constructed by Gravesande. (See his Course of Philosophy.) But a very capital improvement of the air-pump was made in almost all its parts, by the late famous engineer, Mr. John Smeaton; (see his description in the 47th vol. of the Philosophical Transactions); and a well-made pump of that sort, undoubtedly, is one of the best now extant; yet, after the interval of about 25 years, this construction was followed by several other contrivances, some of which are certainly superior to it. The best of those latter contrivances are, a pump by Mr. Haas; (see its construction in the 73d vol. of the Philosophical Transactions); an air-pump by Mr. Prince of Boston in America; (*Encyclopædia Britannica*, article Pneumatics); one by Mr Cuthbertson, an eminent philosophical-instrument

Fig. 18. of Plate XVI. exhibits the simplest sort of air-pump. AB is the brass barrel, which is represented as being transparent for the purpose of shewing the construction of the internal parts. The inside of the barrel is as perfectly cylindrical as can be made, and very smooth. The barrel is open at top, or if furnished with a cover, that cover is perforated for the passage of the rod FG, and of the air. The bottom B of the barrel is accurately closed by a flat piece of brass, excepting a small hole, which passes through the said piece, and communicates with the cavity of the glass receiver D, which is cemented into the piece C, and out of which the air is to be pumped. The small hole in the flat bottom of the barrel is covered by a slip of oil-silk, which is strained over it; whence it appears,

maker, at present in London; (*Encyclopædia Britannica*, article Pneumatics.) A very good improvement of the air-pump was made in France by M. Lavoisier, and other scientific persons, which rendered that engine capable of exhausting to a very great degree; but it is said, that that construction is difficultly executed, and easily put out of order.

The sixth vol. of the *Transactions of the Royal Irish Academy* contains the description of an air-pump, contrived by the Rev. James Little, of Lacken, in the county of Mayo. This paper, besides the particular description of the instrument, contains several good observations on the general subject of air-pumps, and apparatus.

that

that air may pass from the receiver D, into the barrel; but it cannot go from the latter into the former. E is a piston, viz. a solid piece of brass, covered over with leather soaked in oil, or other greasy matter, which fitting the cavity of the barrel very accurately, may be moved up or down all along the barrel, by means of the rod F G, without admitting any air between the surface of the barrel and that of the piston. But there is a hole, indicated by the dotted lines at E, which passes through the piston, and has its upper end covered with a strained slip of oil-silk, similar to the valve at the bottom B of the cylinder. The valve in the piston permits the air's passage from E to G, but not the contrary way. If the hand be applied to the handle F, and the piston be moved alternately up and down the cylinder, the vessel D will thereby be gradually exhausted of air, and the process of it is as follows:

When the piston is drawn upwards, the space between the lower part of it and the bottom of the cylinder is enlarged, and the air in it is rarefied; whereas the air in the receiver D is denser than that; therefore the elasticity or expansive property of this air presses against the lower part of the oil-silk at the bottom of the cylinder, more than the air which is within the cylinder presses upon the upper side of it; hence part of the air of the vessel D passes into the barrel, and of course the quantity of air in D is diminished. Then, by depressing

the piston, the quantity of air which is between it and the bottom of the piston is condensed ; hence it presses against the lower side of the valve G, more than the atmospheric air presses on the upper side of the same ; therefore the greatest part of that air passes through that valve into the atmosphere. When the piston is drawn upwards the second time, the like effect takes place, and the air of the vessel D is diminished a little more\*. Thus, by repeating the movement of the piston, the vessel D is gradually exhausted of air to a certain degree, which is the utmost limit of the pump's exhausting power ; and that degree is expressed by the proportion which the air that lastly remains in the vessel D, bears to that which was at first in it. Thus, if the remaining air is one-tenth part of the original quantity, the pump is said to have rarefied the air ten times ; for, in fact, the remaining quantity of air in D, fills up ten times the space which it occupied before the exhaustion.

\* It will be easily comprehended, that if the valves in the piston and at the bottom of the barrel could be opened with the utmost freedom, the quantity of air, which remained in the vessel D, after every stroke of the piston, would be to that quantity which was in it, previous to that stroke, as the capacity of the vessel D is to the sum of the capacities of that vessel, and of the barrel.

A more particular examination of the parts as well as operations of this pump, will point out the powers, the defect, and the improvements of air-pumps in general.

As the capacity of the barrel is generally small in proportion to that of the vessel, out of which the air is to be exhausted in several experiments, the exhaustion will proceed but slowly; therefore, in order to expedite the operation, pumps have been made with two barrels, which are moved alternately by means of a wheel with a handle, and racks affixed to the rods of the pistons. Both barrels communicate with the same receiver, and the exhaustion goes on as quick again as when one barrel is used.

The receiver cemented to the piece BC, at the bottom of the barrel, cannot be adapted to a great variety of experiments; therefore, instead of that, the barrel or barrels have been made to communicate with the same duct which opens in the middle of a pretty large and flat metal plate. Then a glass receiver of any required size, within certain limits, is placed with its aperture upon that plate, and is exhausted, &c.—In order to prevent the admission of air, between the edge of the receiver and the plate of the pump, it was formerly used to interpose a piece of wet leather, which, however, was found to be prejudicial on several accounts; hence the leather is now seldom used; but the edges of the receiver, as also the surface of the plate, are

ground so very flat and smooth, that when the receiver is placed upon the plate, no air can pass through, especially if the least film of oil be interposed, or be placed on the outside of the edge of glass.

Both those improvements, viz. the double barrel, and the plate, are seen in fig. 17. Plate XVI.

By inspecting fig. 18. Plate XVI. it will also be easily understood, that when the air which remains within the vessel D, is so far rarefied as not to have force sufficient to open the valve at the bottom of the barrel, then the pump cannot exhaust the vessel any farther. This effect is also partly produced by the air which remains between the piston and the bottom of the barrel, when the piston is down. Now in order to avoid these inconveniences, several contrivances have been made, and it is the different nature of those contrivances that forms the variety of those air-pumps which have been mentioned above.

Mr. Haas's last air-pump (for this is not the same as was contrived by the same person some time ago, and which is described in the 73d vol. of the Philosophical Transactions) is shewn in Plate XVI. fig. 2. and 5. The wooden frame of the machine is sufficiently apparent in fig. 2. There are two barrels in it, which by turning the handle H, round the axis A, about one turn and a half one way, and then as much the other way, are worked alternately; for within the wooden part

BB,

BB, there is on the axis A, a wheel with teeth, which catch into the teeth of the racks, which are affixed to the rods of the pistons.

The two barrels communicate with a common duct, which opens in the middle of the Plate P. This plate is firmly fixed upon a wooden pillar that proceeds from the stand or pedestal of the machine. O, O, at the lower part of the machine, are two vessels affixed to the ends of the barrels, and their office is to receive the oil which gradually passes from the inside of each barrel through the valve at the bottom.

Fig. 2. is one-eighth of the real size; and fig. 5. which exhibits a section of one of the barrels, is one-fourth of the real size.

At the bottom V of the barrel, there is a valve which opens outwards, viz. the air may be forced from the inside of the barrel into the atmosphere, but cannot go the contrary way.

The form of the piston is pretty well indicated by the figure. It consists of two pieces of brass screwed together, and holding between them circular pieces of leather, the edges of which rub against the cavity of the barrel. There is a valve in the piston, through which the air may pass from the upper part of the barrel into the lower, but not *vice versa*. The rod of the piston is quite smooth and cylindrical; it passes through, what is called, a collar of leathers, viz. through a hole made in many pieces of leather, which are contained

in a brass box Z, on the top of the barrel.\* Several holes are seen towards the upper part of the barrel, which communicate with a cavity, indicated by two dark lines, that runs all round the upper part of the barrel, and communicates with the duct D of communication with the plate of the machine.

When the piston is drawn upwards, the air may pass, though not very freely, from the upper to the lower part of the barrel, through the valve in the piston; but when the piston is raised so high, as that its lower surface be higher than the above-mentioned holes, then the air from the receiver, which stands on the plate, coming through the duct D, may freely pass into the barrel; for in that case there is neither valve nor any thing else that obstructs its passage. Then on depressing the piston, the air which has entered the barrel being compressed towards the lower part of the barrel, will be forced out of it through the valve at V. It is owing to the freedom with which the air can pass from the receiver which stands on the plate, into the barrel, that this pump rarifies to a very considerable degree.

\* These leathers as well as those of the piston, are well soaked in hog's lard (some workmen soak them in oil and tallow). The latter fit the barrel, and the former fit the outside of the piston rod, so well as not to allow the passage of any air.

It will appear on the least reflection, that no pump can possibly remove all the air from any receiver ; for the quantity of air which is expelled at each stroke of the piston, is only a portion of what was in the receiver previous to that stroke ; and therefore a much greater quantity of air similar in density to that which was last expelled, must remain in the receiver. So that a great degree of rarefaction, but not a complete exhaustion, is all that can be expected from the best pump ; whereas the torricellian vacuum is much more complete than what is made by an air-pump.

When a pump of the common sort rarefies the air of a receiver 200 or 160 times, it may be considered as a very good instrument of the kind. The very best pumps now extant, will rarefy the air 600 or even 800 times ; but I am unwilling to state the most effect of those constructions ; since a very trifling difference generally produces a considerable variation in the result. The pump being recently put together, the valves being more or less strained, the want of a due quantity of oil, between the moving parts of the engine, and various other particulars, render the pump more or less capable of rarefying the air of a receiver ; and generally they rarefy to a great degree at first, but soon lose that power.

The various methods of estimating the quantity of air which remains in the receiver after a certain action

action of the pump, or of measuring the rarefaction, will be shewn in the sequel.

The glass receivers for an air-pump are of different sizes, according to the nature of the experiments. Some of them are open at top, and to their upper aperture there is sometimes applied a flat brass plate, which is ground very smooth, or a socket is cemented; to which plate or socket various apparatuses are affixed.

Sometimes the receivers are not set immediately on the plate of the pump, but they are set on another plate, which has a pipe with a stop-cock, that may be screwed into the centre of the principal plate P. With this apparatus the air of the receiver may be rarefied as well as if the receiver stood upon the principal plate; and when that is done, by turning the stop-cock, and unscrewing it from the middle of the principal plate, that receiver, having the air rarefied, may be removed together with the small plate, and leave the pump ready for other experiments. This auxiliary plate, with its pipe and stop-cock, is commonly called a *transferrer*. See fig. 19. Plate XVI.

Of the various experiments which are usually performed with the air-pump, and which are described in almost all the works on Natural Philosophy, I shall briefly describe a few only, as they will be quite sufficient to indicate the general mode of making such experiments.

Place the glass receiver upon the plate P of the pump, as appears at fig. 2. taking care that both the edge of the receiver and the plate, be quite clean, and smearing the former with a very small quantity of oil; then work the pump by turning the handle H of the machine alternately as far as it will go one way, and as far as it will go the other way. After a few strokes you will find, upon trial, that the glass receiver adheres very firmly to the plate; for as the air is partly withdrawn from the inside of the receiver, the pressure of the atmosphere on the outside becomes manifest. The adhesion of the receiver to the plate increases in proportion as you continue to work the pump.

There is, in every air-pump, a screw-nut on the duct of communication between the barrel and the receiver; which may be opened occasionally, in order to let the external air enter the cavity of the receiver: so that if, in the above-mentioned case, this screw-nut be opened, the air will rush in with an audible noise; in consequence of which the adhesion of the receiver to the plate will be removed.

Under such a receiver, or other receivers of different forms, a variety of things may be placed, and on rarefying the air, different effects will take place; but in describing those experiments, it will be sufficient to say that certain effects are produced by certain substances *in vacuo*; or in the exhausted receiver; meaning such a vacuum as may be pro-

duced by the air-pump; for a more perfect vacuum 'is always denominated the *torricellian vacuum*.

An exhausted receiver does not appear different from what it does before the exhaustion. Objects may be seen in it and through it, just as well in one case as in the other.

A lighted candle placed under the receiver of the pump will go out after a few strokes of the piston, and the smoke will be seen to descend; there being not air enough to support it.

Animals die sooner or later in the receiver of the air-pump. Insects die latest in it, viz. after the lapse of some hours. A dog, a cat, a rabbit, a mouse, a bird, &c. begin to shew signs of uneasiness after a few strokes of the piston; the uneasiness, the quickening of the respiration, and the panting for want of air, increase gradually; vomiting, bleeding at the mouth and nostrils, loss of strength, and swelling of the body, succeed; but all those disagreeable symptoms last not many minutes; for death soon closes the scene.

If previous to their death, air be admitted into the receiver, by opening the screw-nut, the animals generally revive, provided the rarefaction has not broken any vital part.

If water be placed in a glass under the receiver of the pump, on working the machine, the water will at first appear full of air-bubbles, then those air-bubbles enlarge, and coming out of the water, give

it the appearance of boiling. By rarefying the air, and of course removing the pressure of the atmosphere from the surface of the water, the air which is usually contained in it is expanded in virtue of its elasticity, and escapes from the water, which escape gives the appearance of boiling; for the water does not acquire any heat by it.—The like thing happens with several other fluids. If fishes be contained in the water, the rarefaction of the air kills them, and breaks their air-bladders. Even the minute insects that are frequently seen in vinegar, are deprived of life if the vinegar be exposed to the exhaustion of the air-pump.

Shrivelled fruit, under the receiver, are generally swelled by the exhaustion, and appear very plump, whilst they remain in it.

A bladder, containing a very small quantity of air, and having its neck tied up, when placed under the receiver, will, on exhausting the receiver, swell up and appear quite full; the reason of which is, that when the pressure of the atmosphere is removed from the outside of the bladder, the internal air expands itself.

Fig. 4. of Plate XVI. represents a little machine consisting of two little sets of mill-sails, *a* and *b*, which are of equal weights, are unconnected with each other, and turn with equal freedom upon their axes. Each set has four thin sails, fixed into the axis; those of the mill *a* have their planes perpendicular to the axis, those of *b* are parallel to

their axis; in consequence of which when the mill *a* turns round in common air, it is little resisted by the air, whereas the other is resisted in a considerable degree. There is a pin in each axle near the middle of the frame, which goes quite through the axle, and stands out a little on each side of it; upon these pins, the slider *d* may be made to bear, and so hinder the mills from going, when the strong spring *c* is set or bent against the opposite ends of the pins.

This little machine serves to shew the resistance which air offers to the motion of bodies, which resistance is proportionate to the surface that the body presents directly before the air.

For this purpose the above-mentioned little machine, with the springs bent and set upon the axles, is situated upon the plate of the pump, and a receiver is placed upon it; but this receiver must have a socket, with a set or collar of leathers, cemented to its upper aperture, and a long wire must pass through a hole in the leathers, like the rod of the piston in fig. 5; and it must be so situated that the wire of the receiver may be pushed down exactly upon the slider *d*, and discharge it from the pins; in consequence of which the mills being impelled by the spring, will be caused to turn round. Now if this operation be performed when the receiver is full of air, it will be found that the mill *a* will turn round much longer than the other, for it meets with less resistance; but if the same operation

be

be performed when the receiver is exhausted, then the mills will be found to turn for a much longer time, and will stop both at the same time.

The like thing is shewn by the descent of heavy bodies. There is a small apparatus fitted to a brass plate, which is to be situated on the upper aperture of a tall receiver. See fig. 7. of Plate XVI. It consists of wire that passes through a collar of leathers, and has an hooked termination. There is also another wire *a*, which has a moveable flap hinged to its lower extremity. The flap being placed horizontally, may be rested upon the hooked projection of the central wire *b*; then, by turning the wire *b* round its axis, the above-mentioned flap is disengaged from the hooked projection, and drops in a perpendicular direction.

This mechanism is generally called *the guinea and feather apparatus*; because a guinea and a feather, or different bodies of dissimilar specific gravities, are usually placed upon the above-mentioned flap whilst horizontal; and may be dropped from it, by turning the wire *b*. It appears that a guinea and a feather, or any other bodies, will arrive at the bottom of the vessel, or will strike the plate of the pump, at different times when the receiver is full of air; but precisely at the same time, when the receiver is exhausted; in that case, there being nothing in the receiver to resist them, and their gravities being proportionate to their quantities of matter. See page 59 and 60 of vol. I.

Place the glass, AB, fig. 1. Plate XVI. open at both ends, upon the plate of the pump over the hole, &c., and place your hand flat and close to the upper aperture B of it. On exhausting that glass, you will find that the hand is pressed with a weight which increases in proportion as you continue to work the pump, and the adhesion is so great, that the hand cannot be removed, unless the screw-sut be opened, and the air let into the glass.

The cups which are used by surgeons for bleeding, are often applied to the flesh, by means of an exhausting syringe, which is nothing more than a small barrel with piston and valves, exactly like the one described in page 428. This syringe is screwed to the neck of the cup, whilst the opposite and much larger aperture of the cup is applied to the surface of the body, &c.

If instead of applying the palm of the hand, you tie a piece of bladder over the aperture B of the above-mentioned glass, on working the pump, which removes the pressure from the under part of the piece of bladder, the pressure on the external part of it will become very manifest; for the bladder will be hollowed by it, and at last it will be broken with considerable noise.

Fig. 3. Plate XVI. represents a brass machine, consisting of three pieces, A, B, C; which serves to shew the pressure of the atmosphere in a very striking manner. A and B are two hemispherical cups,

cups, which, when joined together, form a globe, the cavity of which communicates with the atmospherical air, through the pipe E, when the stop-cock D is open, otherwise it is absolutely closed\*.

Join the two hemispheres; screw the end of the pipe E, into the centre hole of the plate of the air-pump, and open the stop-cock D. In this situation work the pump so as to exhaust the globe A B; then shut up the stop-cock D, unscrew the pipe E, with the globe from the pump, and screw the piece C upon the pipe E. The globes now being exhausted, the pressure of the atmosphere will force the two hemispheres, A and B, very powerfully against each other; so that if two strong men, applying their hands, one at the upper ring A, and the other at the lower ring C, endeavour to separate them, they will find it very difficult; for if the diameter of the hemispheres be four inches, there will be required a force equal to little less than 200 pounds to pull them asunder. If the globe, thus exhausted, be suspended by either of the rings to an hook within the receiver of an air-pump, and that receiver be exhausted, the

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\* A wet leather, having a hole in its middle, is generally placed between the two hemispheres, in order to close the aperture more effectually; but when they are well made, and their edges are ground properly, a little oil smeared over the edges is quite sufficient for the purpose.

two hemispheres will separate immediately ; shewing, in a most convincing manner, that they adhered to each other merely in consequence of the pressure of the atmosphere.

If you place a barometer under a tall glass receiver of the air-pump, and rarefy the air by working the pump, you will find that the quicksilver descends gradually in the tube of the barometer ; for as the quicksilver is kept up in the barometer by the pressure of the atmosphere on the surface of the quicksilver of the cistern, and its altitude is proportionate to that pressure, therefore, according as the pressure is diminished, so the quicksilver descends in the tube. Now, from what has been shewn above in chap. VIII. it appears, that if the pressure upon the cistern of the barometer be reduced to one half, the height of the mercury in the tube will also be reduced to one half ; if that pressure be reduced to one quarter of its original quantity, then the altitude of the mercury in the tube will likewise be reduced to one quarter of the original altitude ; in short, the altitude of the mercury in the tube of the barometer under the receiver of the pump, is an exact measure of the pressure on the cistern, or of the quantity of elastic fluid that remains in the receiver, or of the elasticity of that fluid ; for the latter is proportionate to the former. Hence the barometer becomes a very good gage of the power of the air-pump, or of the degree of rarefaction ; for the altitude of the

mercury in its tube, is to the altitude of the same at any period of the rarefaction, as the entire capacity of the receiver, or as the air of the usual density, is to the density or quantity of the air in the receiver at that period ; so that if the mercury in the barometer stood originally at 30 inches height, and, after working the pump a certain time, it stands at the altitude of one inch, the conclusion is, that the air within the receiver has been rarefied 30 times, or that the air which remains in the receiver is the 30th part of that which was in it before the working of the pump, since one inch is the 30th part of 30 inches. Thus also, if the mercury in the barometer is found to stand one tenth of an inch above that of the cistern, the conclusion is, that the air has been rarefied 300 times, &c.

Upon this principle three gages have been constructed, viz. *the short barometer gage, the long barometer gage, and the sypbon gage.*

The short barometer gage is nothing more than the lower part of a barometer, viz. a tube of about 8 or 9 inches in length, filled with mercury, and immersed with its aperture into a small quantity of mercury contained in a glass vessel, which forms the cistern. This gage is either placed under the receiver upon the principal plate of the pump, or it is placed under a separate small receiver, upon a little auxiliary plate, which some air-pumps have expressly for that purpose, as in fig. 17. Plate XVI. It is evident that this gage, not being equal to a

whole barometer, will not shew the very small degree of rarefaction; but we are seldom interested concerning these small degrees, and in general this gage will begin to shew the rarefaction when about three quarters of the air have been removed from the receiver, viz. when the air has been rarefied till its remaining elasticity is not able to support that column of mercury. This gage has a scale of inches and parts of an inch affixed to the tube, which shews the precise altitude of the mercury in it.

The long barometer gage is a tube of about 33 inches in length, open at both ends, having its lower end immersed in a cistern of quicksilver, which is fixed on the pedestal, or lower part of the frame of the pump (for the tube itself reaches from that place to the height of the plate). The upper aperture of the tube communicates, by means of a brass tube, with the inside of the pump.

This in fact is an empty barometer, which is filled with quicksilver by withdrawing the air from it through its upper aperture; and if the pump could produce a perfect vacuum, the mercury in this long gage would rise as high as it does in a common barometer; but as the pump cannot exhaust so far, therefore the difference of altitude between the mercury of the long gage, and that of a common barometer, shews the quantity of air that remains in the receiver. This difference of altitude is shewn by a scale of inches and parts of inches,

inches, which is always affixed to the long barometer gage. As the altitude of the mercury in a common barometer, is to the contemporaneous altitude of the mercury in the long barometer gage, so is the whole quantity of air which was in the receiver before the rarefaction, to that quantity which has been drawn out of it.

The syphon gage is nothing more than the short barometer gage, except that instead of terminating in a little cistern, in this gage the tube is bent and rises upwards with its aperture, which by means of a brass tube is made to communicate with the inside of the pump; so that the ascending leg of the tube performs the office of a cistern; hence, in rarefying the air, the mercury descends from the closed end of the tube, and rises into the ascending leg; therefore the altitude of it in one leg above its altitude in the other leg (which leg in fact is the cistern) shews the degree of rarefaction, and this altitude is denoted by an annexed scale of inches and parts of inches. Such a gage is partly seen at g, fig. 2.  
**Plate XVI.**

The above-mentioned gages evidently indicate the elasticity of the fluid, which remains in the receiver of the pump after a certain degree of rarefaction; and it is immaterial whether that elastic fluid be air, or vapour of water, or other elastic fluid; but there is another gage, which from its shape was called, the *pear-gage*, by its inventor, Mr. Smeaton, and which shews (not at the actual time, but after the read-

mission of air into the receiver) how much air was left in the receiver in the preceding rarefaction.

The pear-gage consists of a glass vessel A, fig. 6. Plate XVI. which has a small projecting orifice B, and at the other end is extended into a tube closed at D; the capacity of this tube is the hundredth part of the capacity of the whole vessel. This gage is suspended, with its aperture downwards, to the lower end of a slip-wire (viz.- a wire which passes through a collar of leathers) within a glass receiver of the pump, and exactly under it, a little cup, containing quicksilver, is placed upon the plate of the pump. When the pump has been worked to the intended degree, the air in the pear-gage is evidently rarefied as much as it is in the receiver. In that state, by lowering the slip-wire, the pear-gage is let down till its aperture B has reached the bottom of the mercury. This done, the external air is admitted into the receiver; but it cannot be admitted into the pear-gage, because the aperture B of that gage is now immersed in the quicksilver; but the pressure of the atmosphere on the surface of the quicksilver, forces that fluid metal into the pear-gage, and fills it up to a certain degree E; then the upper part D E of the gage will contain all the air or vapour which occupied the whole cavity of the gage during the rarefaction. There is a divided scale annexed to the upper part D E of the gage, which shews what part of the capacity of the whole gage is filled with air, and of course it manifests

the

the degree to which the rarefaction of the air had been carried. For instance, if we find that the part D E of the gage, which is filled with air above the quicksilver, is the 500th part of the whole; we may conclude, that the air in the receiver had been rarefied 500 times, &c.

But a very considerable difference must be remarked between the indications of this, and of the preceding gages.

When the receiver contains no other fluid besides air, then the pear-gage and the other gages indicate the same degree of rarefaction; but if the receiver contain the vapour of water, or of other liquor, then the pear-gage will indicate a much greater degree of rarefaction than the other gages; because the vapour which has elasticity sufficient to supply the place of air in the receiver, on the readmission of air, is condensed into a space vastly smaller than the same quantity of rarefied air can be condensed into; so that the pear-gage shews the quantity of air alone which had been left in the receiver; whereas the other gages shew the quantity of elastic fluid which is actually remaining in the receiver.

Fig. 16. Plate XVI. represents a vessel proper for weighing air. It is a glass vessel in the shape of a Florence flask, having a socket of brass with a stop-cock cemented on its neck. The aperture A of the brass part is formed into a screw, which fits the screw in the middle of the plate of the pump.

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This vessel, being screwed on the pump, and the stop-cock B being opened, is exhausted; then the stop-cock is turned so as to shut up the aperture, the vessel is unscrewed from the pump, and is weighed in an accurate pair of scales. This done, the stop-cock B is opened, and the air is admitted into the vessel, which is then weighed again, in which state it will be found to weigh more than it did in its exhausted state. The difference of the two weights is the weight of a quantity of air, of the actual density of the atmosphere, equal in bulk to the capacity of the vessel. Yet, since no air-pump produces a perfect vacuum, the above-mentioned vessel, in what we have called its exhausted state, does actually contain a small quantity of air, which renders the result inaccurate. But this inaccuracy may be corrected in a very easy manner, by observing the precise degree of rarefaction, as indicated by the gage, and allowing for the remaining quantity of air. Thus, for instance, suppose that the gage indicates that the air has been rarefied 80 times; therefore the air which remains in the vessel, is the 80th part of its whole capacity. In this state let the vessel weigh 9000 grains, and when full of air, let it weigh 9160 grains, the difference of which weights is 160 grains, and this is the weight of a quantity of air equal to  $\frac{1}{80}$ ths of the capacity of the glass; therefore the 160 grains must be increased by the 80th part of that number, viz. of 2 grains, then the sum, which is 162 grains, is

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the weight of a quantity of air equal to the whole capacity of the vessel.

If instead of weighing common air, in the above-mentioned vessel, it be required to weigh some other sort of permanently elastic fluid, the operation must proceed as above, excepting that before the stop-cock B be opened, previously to the second weighing, the end A must be screwed or fastened to the neck of a bladder, or other receiver, full of that other sort of elastic fluid; so that the vessel may be filled with it, instead of common air. It is then weighed again, &c.

### *The Condensing Engine.*

The principle of the condensing engine will be easily comprehended; for if in the exhausting engine, fig. 18. Plate XVI. the valves be reversed, viz. the valves at B, and at G in the piston, be turned upside down, that engine will become a condensing engine; since in that case, when the piston is drawn towards A, the air will rush through the valve at E, into the barrel; and when afterwards the piston is pushed downwards, the air of the barrel will be pushed through the valve at B, and will be condensed into the vessel D. Yet an exhausting syringe is made in a manner still more simple; see fig. 15. of Plate XVI. The cylinder has one valve at its lower aperture B, which opens outwards;

outwards ; the piston is not perforated, but solid, and there is a hole on the side of the barrel, at C. When the piston is drawn upwards, a vacuum is formed in the lower part of the barrel ; but as soon as the lower part of the piston is raised above the hole C, the air rushes through that hole, and fills the barrel; then, on lowering the piston, the air is condensed into the lower part of the barrel, and is forced out at B, into any vessel, to which that end of the syringe is screwed. With this syringe the air is condensed into the inside of a water fountain, or of a wind-gun, which instruments are so commonly described in philosophical works, &c. that they need not be inserted in this place. But for the purpose of performing a variety of philosophical experiments in condensed air, such a syringe is adapted to a frame and apparatus, as at fig. 1. Plate XVII. and this apparatus is commonly denominated a *condensing engine*.

CD is a brass condensing syringe, which, when by applying the hand at Z, the piston is moved alternately up and down, forces the air through the brass pipe D N F, into the glass receiver A B. This receiver must be very thick, and well annealed : it is set with its smooth and flat edge on the plate of the machine, which is similar to the plate of an air-pump ; a thick piece, L M, of brass, is applied in a similar manner to the upper aperture of the glass receiver, and a slip-wire passes through a collar of leathers in this brass piece. As the force of the condensed

condensed air would lift up the brass piece, L M, from over the receiver, or lift up the latter from the plate, so the receiver and brass piece are kept down by the cross piece of wood G H, which is adjusted by means of the screw-nuts on the steady pillars I, K.

There is a gage, E F, annexed to this machine, which indicates the condensation of the air within the receiver and tube of communication. It consists of a strong and narrow glass tube hermetically closed at E, and connected with the brass pipe of communication at F. A small quantity of quick-silver fills up a short part of the cavity about the middle of the tube, and the space between the mercury and the closed end E of the tube, contains air of the usual density. Now when the air is condensed in the receiver, in the tube of communication, &c. the mercury is thereby impelled farther towards E, and the contraction of that space, which is shewn by an annexed scale, shews the degree of condensation; for instance, if the air which is contained in that space is, by the condensation, forced into half the space it occupied before, the conclusion is, that the air within the receiver is as dense again as it was previous to the condensation; and this is generally expressed by saying, that then the receiver does contain two atmospheres; if the air at E be contracted into a quarter of its original space, then four atmospheres have been forced into the receiver; and so on \*.

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\* The condensation is inversely as the space occupied by the air at the extremity E of the gage.

Certain air-pumps, as that of Mr. Smeaton, and the first which was contrived by Mr. Haas, can be made to exhaust or to condense at pleasure, which is done by changing the communication between the cylinders and the plate of the pump; for as in those pumps the air is rarefied towards one end, and is condensed towards the other end of each barrel, the machine will exhaust if the former end of the barrel be made to communicate with the plate of the pump, and the latter with the atmosphere; but it will become a condenser, if the latter end of the barrel be made to communicate with the hole in the centre of the plate, and the former with the atmosphere.

## CHAPTER XV.

CONTAINING THE PRINCIPLES OF CHEMISTRY, AND  
PARTICULARLY THE DESCRIPTION OF THE PRIN-  
CIPAL OPERATIONS AND APPARATUS.

CHEMISTRY is the science which endeavours to ascertain the number, the quantities, and the properties, of the constituent principles of all natural bodies. It also endeavours to form new or artificial compounds.

The separation of the component principles of a body from one another, is called *analysis*. The formation of compound bodies from simpler substances, is called *synthesis*.

Both the analysis and the synthesis are performed by means of certain operations, which are therefore called *chemical operations*, or *chemical processes*.

It has been said above, page 19. that there is a mutual attraction between the parts of the same substance, which is called attraction of aggregation; and that there is, likewise, a mutual attraction between the heterogeneous parts of different bodies, which, when it is merely superficial, is called *attraction*

*attraction of cohesion; but it is called attraction of affinity, or of composition, when it produces an intermixture of two or more heterogeneous substances, and a change of some, at least, of their properties.*

Now it must be remarked, that the affinity of one substance to another, differs in degree according to the different substances; and it is upon the difference of those affinities that the operations of chemistry are established; for if the affinity between two bodies were equal to the affinity between any two other bodies, chemistry could not exist. Thus for instance, it is known that A and B have a certain degree of attraction or affinity towards each other; also, that there is a greater affinity between A and C; and a much greater affinity between C and D. Now, if I wish to analize a certain body, which is a compound of A and B, I mix that body with the body C, in consequence of which, as C has a greater affinity to A than to B, the given body will be decomposed; and one of its ingredients, viz. A, will form a new compound with C, whilst the other ingredient B will be left by itself. Then I mix the new compound of A and C, with D, in consequence of which this new compound will be decomposed, C will adhere to D, and A will be left by itself. Thus I obtain A and B, viz. the two components of the given body, in a separate state.

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The attraction of aggregation counteracts, or is opposite

opposite to the attraction of affinity; for the weaker one of them becomes, the greater power will be gained by the other.

The attraction of affinity acts more powerfully in proportion as the quantity of contact between the different bodies is increased; hence the action between two bodies that have a certain affinity, is weak or imperceptible when both the bodies are in a hard solid state; it becomes stronger when the bodies are softened by means of heat, (which diminishes the attraction of aggregation) or when they are pulverized and intermixed:—stronger still, when one of the bodies is in a fluid state; and it will become as active as possible, when both the bodies are in a fluid state. Therefore, in order to decompose, or to compose, different bodies, it is necessary to pulverize, or to heat, or to mix, or, in short, to perform diverse operations with a variety of necessary instruments, according as may be required by the nature and properties of the different articles. Hence the whole subject of chemistry consists, 1st, of the art of performing the necessary operations; and 2dly, of the knowledge of the principal facts, which have been ascertained by means of those operations. The second of those objects is what immediately belongs to the present part of these elements of natural philosophy, which treats of the peculiar properties of bodies; we shall nevertheless premise a competent account of the principal operations, through which most of the peculiar pro-

properties of bodies have been ascertained, and by the means of which new discoveries may be made.

*Trituration, pulverization, and levigation,* (viz. the reduction of solids into powders of different fineness) are performed by means of the hammer, rasps, files, graters, mortars and pestles, or a flat stone and muller. Most of those tools, viz. the hammer, mortars, pestles, stones and muller, are either of wood, or metal, or glass, or porcelain, or marble, or agate, &c. according to the hardness and other properties of the articles that are to be pulverized. But these must be considered amongst the preliminary operations; for they only alter the bulk, and not the nature of the articles; since every particle of a pulverized body is a small whole of that body; whereas the real chemical operations destroy the aggregation of bodies, separate their constituent principles, form new compounds, and alter some of, if not all, their properties.

The separation of the finer parts of bodies from the coarser, which may want farther pulverization, is performed by means of *sifting*, or *washing*.

A *sieve*, for sifting, generally consists of a cylindrical band of thin wood, or metal, having across its middle a perforated diaphragm of silk, or leather, or hair, or wire.

Sieves are of different sizes and different fineness. Fig. 3. of Plate XVII. shews a sieve of the best construction. It consists of three parts, A, B, C. The middle part B is properly the sieve; D is the perforated diaphragm, through which the powder

passes ; C is a bottom which may be put on, or taken off, the lower part of B, and serves to receive the powder that passes through the sieve ; A is a top or lid, which is placed on the upper part of B, and serves to prevent the falling off, or the dissipation into the air, of the materials. When all the three parts are together, the shape of the sieve is as in fig. 7. Plate XVII.

By washing, one may separate powders of an uniform fineness much more accurately than by means of the sieve ; but it can only be used for such substances as are not acted upon by the fluid which is used. The powdered substance is mixed with, and is agitated in, water, or other convenient fluid ; the liquor is allowed to settle for a few moments, and is then decanted off ; the coarsest powder remains at the bottom of the vessel, and the finer passes over with the liquor. By repeated decantations in this manner, various sediments are obtained of different degrees of fineness ; the last, or that which remains longest suspended in the liquor, being the finest.

*Filtration* is a finer species of sifting. It is sifting through the pores of paper, or flannel, or fine linen, or sand, or pounded glass, or porous stones, and the like ; but it is used only for separating fluids from solid or grossish particles, that may happen to be suspended in them, and not chemically combined with the fluids. Thus salt water cannot be deprived of its salt by filtration ; but muddy

water may. No solid, even in the form of powder, will pass through the above-mentioned filtering substances ; hence, if water or other fluid, containing sand, insects, mud, &c. be placed in a bag, or hollow vessel, made of any of those substances, the sand, &c. will remain upon the filter, and the liquor will pass clear through the filter, and may be received in a vessel placed under it\*.

*Lixivation* is the separation by means of water, or other fluid, of such substances as are soluble in that fluid, from other substances which are not soluble in it. Thus, if a certain mineral consist of salt and sand, or salt and clay, &c. the given

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\* Filtering paper is paper without size. For this purpose the piece of paper is shaped into the form of a cone, and is placed into a funnel, in order to support it, otherwise, when wet, it would easily break.

Filtering stones and filtering basons, either natural or artificial, for the purpose of purifying water, are not unfrequently used in this and other countries. Rocky mountains, beds of sand, gravel, &c. are natural filters.

The composition for making filtering basons for purifying water, consists of equal parts of tobacco-pipe clay, and coarse sea, river, drift, or pit sand. The basons are formed and turned on a potter's wheel. They should be about  $\frac{1}{4}$  of an inch thick. When the vessels are of the usual degree of dryness, the whole outside and inside surface must be shaved or turned off on a potter's wheel ; and, when perfectly dry, those basons are burnt or baked in a potter's kiln after the usual manner.

body

*Description of the principal Operations, &c.* 501

body being broken into powder, is placed in water, which will dissolve the salt, and keep it suspended, whilst the earthy matter falls to the bottom of the vessel, and, by means of decantation, may be separated from the fluid. If the salt, or other substance, which is dissolved in the fluid, be required to be separated from it, then recourse must be had to

*Evaporation*, which separates a fluid from a solid, or a more volatile fluid from another which is less volatile.

*Simple Evaporation*, properly speaking, is used when the more volatile or fluid substance is not to be preserved; and, in that case, the evaporation is performed in vessels of wood or glass, or porcelain or metal, &c. which are either simply exposed to the air, or are placed upon a fire, more or less active, according to the nature of the substances.

When the fluid, which is evaporated, must be preserved, then the operation is called *distillation*, and is to be performed in other vessels, which are called *retorts*, *alembics*, *stills*, &c. made either of glass, or porcelain, or metal, &c.

The office of those vessels is to condense the vapour into a liquid form, and to convey it into a recipient. The evaporation is performed by means of heat;—the condensation by means of cold; therefore the body of any of those vessels, which receives the materials, must be placed upon a fire, or hot

place; but that part of the vessel which condenses the vapour, and is hence called the *refrigeratory*, must be rendered sufficiently cool for the purpose.

Fig. 2. Plate XVII. represents a retort. In this distilling instrument, the materials are placed in the body E A F, and the bottom A is placed upon the fire\*. The vapours which rise from the materials at E F, pass through the tube E B C, which being at some distance from the fire, and therefore cooler, condenses the vapour into liquid drops, which, on account of the inclination of the tube B C, run down into the recipient D, which is adapted to the neck of the retort †. Thus the solid part of the materials in E A F remains in the retort, and the fluid part passes over into the receiver.

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\* In order to prevent its breaking, the bottom of the retort is generally covered with some adhesive substance, which can stand the fire, such as clay, a mixture of lime and clay, &c. this is called *luting* the retort; or the retort is placed in a basin of sand or water, and this basin is then placed immediately upon the fire.

† The receiver must not, in most cases, be closed very accurately upon the neck of the retort; for that may occasion the bursting of the instrument; but when that accurate closing is practicable, it may be accomplished by the application of wet paper, or wet rags, or a mixture of wax and turpentine, or a mixture of whitening and oil, &c.

This instrument is used when the quantity of materials is small; and the vapours may easily be condensed; otherwise an alembic, such as fig. 4. Plate XVII. is used. This instrument consists of two parts. AB is the body which receives the materials. AC is the capital, which is joined close to the body. The upper part of the capital is formed into a bason C, in which cold water is placed, which condenses the vapour in the cavity ; so that the drops of liquor fall in the groove o, o, and come out of the tube D into the recipient. In distilleries and other large works, the capital has not the bason or refrigeratory C ; but the tube D is made very long, and is shaped into a screw-like form, called *a worm*, which is placed into a tub of water, and has its aperture out on one side of the tub. Then that worm and tub forms the refrigeratory.

When the materials which are evaporated in the body of the distilling vessels, concrete not in a fluid but in a solid form, within the neck of the retort or tube, &c. then that distillation is more properly called *sublimation*.

By the above means one fluid may be separated from other materials ; but it often happens that in distillation several fluids are produced, some of which are permanently elastic, and all or most of them may be required to be preserved. In this case, another sort of apparatus must be used, which is called

*The Apparatus for Pneumato-chemical Distillations.*

See fig. 5. Plate XVII. A is a tubulated retort\*, adapted to the recipient B, which has two necks. To the upper neck of this recipient is fitted a bent tube C D E, whose other extremity reaches as far as very near the bottom of the recipient G. This recipient has three necks *a*, *b*, *c*, into the first of which the end of the tube D E is fitted; into the second, *b*, an open tube, which reaches very near the bottom of G, is fitted; and to the last neck, *c*, a crooked tube is adapted, which opens and discharges the elastic fluid into a proper receiver. Sometimes two or three, or more, vessels, like G, are interposed; viz. instead of the crooked tube F, a tube, like C D E, is adapted to the vessel G, and to the next which is similar to it, and so on; then the crooked tube F is applied to the last neck of the last of those vessels.

When this apparatus is properly connected, the materials are put into the retort through the hole O, and a proper degree of heat is applied to the bottom of the retort; then the products will be collected in different parts, viz. what is sublimed, or concreted, in a compact form, adheres to the neck of the retort; the fluid of easiest condensation is collected into the receiver B; the elastic vapours,

\* When the retort has a hole and stopple, as at O, which is useful for introducing or stirring the materials; it is then called a *tubulated retort*.

which

which are condensable in water, will be combined with the distilled water, which must be placed at the bottom of the vessel G, and those which are not susceptible of being thus absorbed, pass through the tube F into a proper receiver, or they may be made to pass through other successive vessels similar to G, in which such other fluid may be placed, as may be capable of absorbing one or more of the permanently elastic fluids. The tube H serves to admit some atmospheric air, in case the water in G should absorb the produced elastic fluid too quickly.

In certain cases of mixtures, the produce is merely an elastic fluid, which is required to be collected. For this purpose, the vessel represented in fig. 6. Plate XVII. is very useful. It consists of a body A, to which a perforated stopple, with the crooked tube C, is adapted. The materials are placed in A, and the elastic fluid which is generated, passes through B C D, into a proper receiver.

Such receiver, and the rest of the apparatus proper for receiving, measuring, mixing, and performing other operations on permanently elastic fluids, is delineated in fig. 8. Plate XVII. A B C D E is a wooden trough, having a shelf F, G, and filled with water as high as about an inch or two above the shelf. There are several glass jars, or receivers, as H, I, K, L, which serve for retaining, mixing, measuring, and otherwise

using the permanently elastic fluids. Those jars are first filled with water in the trough, then they are turned upside down, and being lifted up gently, so as not to elevate their aperture above the water, they are placed upon the shelf, as represented at G. Then if a vessel full of air be placed with its aperture downwards into the water of the trough, and there it be turned upside down, just under one of the jars full of water, the air or permanently elastic fluid being the lighter fluid of the two, will ascend into the latter vessel, and all or part of the water will come out of it, according to the quantity of air introduced.

For the purpose of rendering this operation more commodious, some holes are seen in the shelf, which are the apertures or apexes of as many inverted funnels, or little domes dug out of the thickness of the shelf; so that when a vessel full of air is inverted under one of those holes, whereupon a jar full of water is placed as at G, the air will come out of the former vessel, and passing through the hole in the shelf, will enter the latter vessel.

At F there is represented a jar which receives the air that is generated from the materials in the phial M, similar to the phial, fig. 6. There the phial is represented as heated by the flame of a candle, which in several experiments must be done, in order to assist the extrication of the elastic fluid. This fluid is conveyed through the crooked tube, and is discharged under one of the holes of the shelf through

through which it passes into the receiver I, and in proportion as the elastic fluid ascends under the form of bubbles, the water subsides.

A small glass vessel L, capable of containing about an ounce measure, is used as a measure of a permanently elastic fluid; for if this phial be successively filled and inverted under a large jar, we may thereby throw into that jar any required quantity of an elastic fluid, or as many measures of one elastic fluid, and as many of another, as we please.

When a glass jar is partly filled with an elastic fluid, we may measure the quantity of that fluid by measuring the diameter and altitude, or the capacity of that part of the vessel, in the usual geometrical way of gauging vessels. But for the sake of greater expedition and accuracy, the contents of a vessel are sometimes marked on the outside of it. Thus the tube, or narrow vessel, K, is marked on the outside, shewing the space which is occupied by each successive measure of air, such as is contained in the measuring phial L. Such a vessel as K is mostly employed for examining the purity of common or respirable air. This is done by mixing a certain quantity, as a measure or two, of respirable air, with a certain quantity of another permanently elastic fluid, or of some other substance capable of occasioning a diminution of the bulk of the elastic fluid, and then measuring the diminution; for the purity of the respirable fluid is proportionate

proportionate to that diminution. The parts of a measure are sometimes marked upon the tube K itself, and at other times are ascertained by the external and occasional application of a divided scale. The tube K, or in general any such vessel as is used for ascertaining the purity of respirable air, is called an *Eudiometer*.

It is sometimes required to remove an inverted jar with its contents from the shelf of the trough: this is done by the use of a shallow pan or dish, which is immersed in the water of the trough, and the jar is slipped in it; then the whole may be removed and placed wherever it may be convenient, as at P. In this case the shallow pan performs the office of a small trough; and for such purposes several dishes or pans of different sizes should be had in readiness.

Some elastic fluids are inflammable, and in order to try their inflammability a small phial may be filled with any of them, and after having stopped its aperture with a finger, it may be removed from the water; then being brought with its aperture near the flame of a candle, the finger is removed, and the elastic fluid will take fire, as may be clearly seen in the dark, and even in the day light. When the quantity is not very small, a pretty large jar is filled with it, and the palm of the hand is applied to the aperture; in that situation the jar is removed from the water, and is turned with the aperture upwards. Then having in readiness a twisted wire

with a bit of lighted wax taper at its extremity, the hand is removed, and the lighted taper is dipped in the vessel, &c. as shewn at Q.

Some of the permanently elastic fluids are absorbed by water; therefore they cannot be confined by water. For such fluids, it becomes necessary to use a trough full of quicksilver; but on account of the price and weight of the mercury, a much smaller trough and smaller glass vessels must be used.

The solution of salts in water, the dissolution of metallic and other substances in different menstrua, require a variety of vessels, whose form, viz. whether open or close, or deep, &c. is easily suggested by the nature of the articles.

When a salt is dissolved in water or other fluid, and by evaporation the fluid is driven off, the salt gradually acquires the solid form, and in doing this it arranges its particles in a particular manner; as, for instance, some salts arrange themselves under the form of cubes, other under the form of globules, &c. The same thing happens with some earthy particles, and several other substances. Now this spontaneous regular arrangement is called *crystallization*\*.

Vessels, generally open, but sometimes closed, are employed for such crystallizations; and the cry-

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\* See the Abbe Hauy's Work on the Structure of Crystals.

talization of some substances requires a certain temperature, that of others requires an higher, or a lower temperature ; hence the charged vessels must be placed in cool places, &c.

The fusion of metallic substances by means of heat, requires vessels sufficiently strong to resist the fire. Those vessels are mostly, if not always, made of earthenware or porcelain, or a mixture of clay and powder of black-lead. They are called *crucibles*, and their more usual shapes are represented at fig. 9. Plate XVII.

Some of those crucibles have covers likewise of earthenware ; but sometimes the fused metal must be exposed to a current of air. In that case the proper crucibles are shallow and broad, as at fig. 10. Plate XVII. These are called *cuppels*, and they are formed either of calcined bones, mixed with a small quantity of clay, or of a mixture of clay and black-lead powder. But the cuppels must not be placed in a close furnace, or be surrounded by coals ; for in that case the required current of air could not have access to the fused metal. They are therefore placed under a sort of oven of earthenware, which is called a *muffle*, as represented at fig. 13. Plate XVII. and the muffle, containing the cupples, &c. is exposed to the fire of the proper furnace.

The various degrees of heat, which are required for the performance of chemical operations, viz from the heat of a small wax taper, to that of the

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most powerful furnace, render a variety of fire-places or furnaces necessary for a chemist. Those furnaces are either open at top, or they are covered with what is called a *dome*, and have a chimney, or tube, to carry off the heated air, smoke, &c. They are sometimes supplied with air from the natural action of the fire, which rarefies the air about the ignited fuel, and the rarefied air becoming specifically lighter, ascends into the chimney, and other colder, and consequently heavier, air, is forced by the atmosphere to enter at the lower part of the furnace. Some furnaces are supplied with air by means of bellows; and those are applied for forging iron, or for reducing metals from the ore, which is called *smelting*, &c. Hence the furnaces derive their various names, and are called simple, or open, furnaces; reverberatory furnaces; wind, or air, furnaces; blast, or bellows, furnaces; forges; smelting furnaces, &c.\*

When a pan full of sand, or of water, is placed over a common furnace, and a retort, or other vessel, is placed in the sand, or water; that mode of applying heat is called a *sand bath*, or *water bath*.

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\* The particular description of the various furnaces may be seen in a variety of chemical works: Macquiar's Dictionary of Chemistry, and Lavoifier's Elema, of Chem. are some of the best for this purpose.

There are several other chemical operations, expressions, and tools, which are so obvious, common, or simple, as to need little or no particular explanation. The following are the most remarkable.

The *dry way* of performing chemical operations, is when strong degrees of heat are used, and the *humid way* is when fluid solvents, and at most low degrees of heat, are used.

*Combustion* is when a body is burned with the assistance of respirable air. *Deflagration* is when the combustion is attended with little explosions or cracklings. *Detonation* is a pretty loud report.

The word *mixture* is commonly understood ; but the mixing of bodies, which have a great affinity to each other, requires a variety of precautions ; for sometimes such mixtures are attended with heat, ebullition, explosions, and such like dangerous effect. They must, according to the nature of the materials, be made either slowly, or suddenly, in open vessels, or closed phials ; they must sometimes be assisted by agitation, stirring, heating ; and at other times must be left undisturbed ; but the time and the mode of adopting any one or more of those particular applications, must be learned from practice, and from a competent knowledge of the nature of the ingredients.

When a solid substance in powder, or otherwise, is left for a certain time in a fluid, and the mixture is  
kept

kept exposed to a slow degree of heat; that process is called *digestion*.

When a substance, which has an affinity to another substance, is mixed with as much of that other substance, as its affinity will enable it to hold in combination, then the former substance is said to be *saturated*, or the mixture to have attained the point of *saturation*. If the mixture contain a greater proportion of either substance, then that mixture is said to contain an *excess of*, or to be *surcharged with* that other substance. The same thing must be understood of the compounds of more than two substances.

THE grand principle of all chemical processes, which enables us to decompose certain bodies, and to compound others, is that *every substance has a certain peculiar affinity for other substances, not in equal degree.*

This principle, though long known, could not however, be universally applied to explain the variety of chemical phenomena, on account of the undiscovered nature of several powerful affinities, and on account of the supposed attraction of others which have no real existence.

The wrong or confused knowledge respecting heat, fire, air, light, &c. rendered a vast number of facts absolutely inexplicable; certain effects appeared to be contradictory; some seemed to have nothing to do with the principle of affinity; others were explained upon the supposed attraction of

the knowledge, and even the errors, of their pre-decessors, having investigated, with infinite labour and ingenuity, the nature of those powerful natural agents, have found reason to explode the supposed existence of the phlogiston, and have been able to form a theory, which is incomparably more general, less complicated, and more satisfactory, than any other preceding theory.

This theory considers every process, which produces a change of some or of all the properties of the bodies in action, as depending on the various elective attractions of those bodies, or of their components; and, in general, the result of every such process is the decomposition of certain compound bodies, and the formation of others.

Not only the mixtures of metallic substances with acids or alkalies; the formation of soaps, the formation of compound salts, the purification of metals, and such other operations as are performed in chemical laboratories; but whatever composition or decomposition, with change of properties, takes place in nature, such as the burning of combustible bodies, the rusting of iron, the evaporation of water, animal respiration, the growth of animal and vegetable bodies, their fermentations and putrefactions, &c. have, in great measure, been proved to depend, (and, by analogy, we are led to believe that they do all depend) upon the elective attractions of the various ingredients.

A few examples will be necessary to illustrate

this doctrine: but those will be found in the next Chapter; for in this we must state some general observations on the nature of the primitive or elementary substances, which are the agents in all natural and chemical processes. A list of those substances has been inserted in the first volume of this work, as also in the present volume, pages 15 and 16, to which the reader is referred.

The *light* which is perceived by our eyes, is supposed to be the effect of a peculiar fluid, which proceeds from the sun, a candle, a fire, or other luminous object. We cannot confine it in vessels, nor can we weigh it, nor measure its quantity, excepting in some degree by comparison, viz. of two luminous bodies, we may determine which is the most luminous. But light seems to enter into combination with certain bodies, and by that combination to produce particular effects; for instance, plants that are kept growing in the dark, lose their green colour, and become white or pale. Plants which grow in confined places, always endeavour to turn their tops and tender branches towards the light; — their flavour, their vigour, their fragrance, are much greater when they have been exposed to much light in the course of their vegetation, than otherwise.— There are likewise several other effects produced by light in various chemical processes.

*Caloric* is supposed to be a peculiar fluid, which produces in us the sensation of heat. We can neither weigh it, nor confine it in vessels. A greater

or less quantity of it is contained in bodies of every sort. It passes through all sorts of bodies, but easier through some, such as the metals, than through others, such as charcoal, wood, &c. hence certain bodies are said to be better or worse *conductors* of heat than other bodies.

*Caloric* enters into combination with various substances; viz. it possesses peculiar affinities; and very ingenious methods have been discovered for ascertaining the comparative quantities of it, which are absorbed, retained, or disengaged in a great variety of processes. As a mixture of two substances must naturally have a greater bulk, than either of them singly; so by the accession of caloric a body is enlarged in its dimensions, and, of course, from their being placed farther from each other, the attraction of aggregation between the constituent particles of that body is weakened: hence every body is expanded by heat, and is rendered more or less consistent by the accession of various degrees of caloric. Amongst those various degrees of consistency, we distinguish three principal states, viz. the solid, the liquid, and the aërisome state. Thus water, according as more and more caloric is communicated to it, assumes, first the solid state of ice, next that of fluid water, and then the aërisome state, or what is called *vapour* \*. If pressure,

or

\* It is not unlikely that by a further expansion, and perhaps by the combination with the electric, or other fluid,

or the contact of other bodies, which have a greater affinity for caloric, come into contact with a substance in a state of vapour, that substance becomes a liquid, and then a solid, harder and harder.

Certain bodies, when they have acquired a quantity of caloric sufficient to give them an aërisome state, hold it with so much force, that neither pressure, nor the contact of colder bodies, can take it away, and convert them into a liquid; in that case they are said to be *permanently elastic fluids*, otherwise they are called *vapours*.

When caloric is communicated to a body, that body will absorb as much of it as its peculiar affinity will enable it to absorb, and the rest will tend to expand itself equally through all the surrounding bodies.—The former portion is called *combined caloric*, and the latter has been called *free caloric*, because its transition to other bodies becomes sensible from the effects it produces on those bodies; viz. those other bodies are expanded, or softened, or liquified by it. This effect of expanding bodies furnishes the best means of measuring heat or free caloric; and the Thermometer acts upon this principle. The quantity of combined caloric is measured in the same manner as, by analyzing, we separate, and measure, the quantity of any other ingredient; viz.

the vapour of water may become more permanently elastic, at least so as not to be condensable into fluid water merely by mechanical pressure, or cooling.

the given body A is mixed with some other body B, that has a greater attraction, or affinity, for A, than A has for caloric; in consequence of which that latent, or combined caloric of A, is separated from it, and becomes free caloric, or sensible heat; and its quantity may be measured from the effect it produces on the Thermometer, or upon other contiguous bodies.

The *electric fluid* seems to be another remarkable agent in nature. Its action seems to be very extensive. It has no perceptible weight, nor can we exhibit it by itself. It passes more or less freely through certain bodies, and not at all, or perhaps difficultly, through others. Hence the former bodies are called *conductors*, and the latter *non-conductors*, of electricity. It is developed or absorbed in a variety of natural and artificial processes: hence it seems to have peculiar affinities; but the facts which have been discovered, though numerous, do not enable us to form any distinct and comprehensive notions with respect to its real and general agency.

The *magnetic fluid* is much more hypothetical, and more partial in its action, than any of the former. This is supposed to be a fluid which, excepting in very few cases, affects iron alone, or such bodies as contain iron, and produces those effects which are called *magnetic*, and which are all reducible to two, viz. to an attraction (not an attraction of affinity) between certain parts of ferruginous

bodies, and to a repulsion between certain other parts of the same bodies.—We have no knowledge of this fluid entering into combination with any body, nor of its producing any other effect.

Of those four natural agents, viz. heat, light, electricity, and magnetism, particular notice will be taken in the next volume. What has been already said concerning their nature, is sufficient to illustrate the subject of the remaining pages of the present volume.

There seem to be only three principal and permanently elastic fluids in nature, each of which consists of a simple substance combined with caloric, and, probably, with light:—they are called *oxygen air*, *hydrogen gas*, and *azotic gas*, or *nitrogen gas*\*; and their bases, or peculiar constituents, independent of the caloric and light, are called *oxygen*, *hydrogen*, and *azote*, or *nitrogen*. But there are several other aërial fluids, some of which are combinations of the above-mentioned three, with other substances. The following list contains their number, their names, and the ingredients of them all, besides caloric and light.

*Oxygen gas, or pure vital air.*

*Atmospheric air, consisting of about 28 parts of*

\* The name *air* has been more particularly given to the respirable fluids; whereas the word *gas* is a more general appellation for permanently elastic fluids, particularly for those of a suffocating quality.

oxygen air, and 72 of azotic gas.—Those two fluids are fit for respiration, and, of course, for supporting animal life; all the rest being suffocating, and unfit.

*Azotic gas.*

*Nitrous gas*, consisting of azote, combined with a little oxygen.

*Oxygenated muriatic gas*, consisting of muriatic acid, surcharged with oxygen and deprived of water. This is the only aërial fluid which has a little colour, viz. a greenish-yellow tinge. All the others are colourless.

*Carbonic acid gas*, consisting of carbon dissolved in oxygen. This, and especially the four following, are absorbible in great quantities by water.

*Muriatic acid gas*, being muriatic acid deprived of its superabundant water.

*Sulphurous acid gas*, being sulphuric acid that has lost part of its oxygen, and also lost its superabundant water.

*Fluoric acid gas*, being fluoric acid deprived of its superabundant water.

*Ammoniacal gas*, being ammonia (or caustic volatile alkali) deprived of its superabundant water.

*Hydrogen gas*. This and the four following, are inflammable.

*Sulphurated hydrogen gas*, (or *bepatic gas*) consisting of sulphur dissolved in hydrogen.

*Phosphborated hydrogen gas*, consisting of phosphorus dissolved in hydrogen.

*Carbonated*

*Carbonated hydrogen gas*, consisting of hydrogen, and the base of carbonic acid gas.

*Hydrogen gas of marshes*, consisting of hydrogen and different proportions of azote.

Those are the principal elastic fluids, or those which occur more commonly. Mixtures of two or more of them are infinite in number; but the ingredients may be separated more or less by various means, and thus their quantities may be ascertained. Those means must be derived from their peculiar properties; for instance, if a mixt elastic fluid be agitated in water, the water will absorb that which is of a saline quality, and will leave the other by itself. Then the latter, by the application of a lighted candle, will shew whether it be inflammable, or capable of assisting combustion, or incapable of it, &c.

The purity of the atmospherical fluid, which is various at different times and places, is tried by exposing to a determined quantity of it, such substances as have great affinity for the oxygen part; for by this means the atmospheric air is decomposed, the oxygen combines with the other substance, and the azotic gas remains by itself; and its quantity determines the purity of the air, or rather the ratio of azote to oxygen; for the air may be rendered unfit for respiration by the suspension of other substances, which do not diminish the proportion of oxygen in it.

*Carbon*, or the carbonaceous principle, is pure charcoal,

charcoal, and seems to be a simple substance; for it has never been decomposed. It exists in vegetables, as also in animal bodies, and may be separated from the oily and volatile principles by distillation, as also from the salts, by washing in pure water.

*Sulphur* seems to be a pure substance. It exists principally amongst minerals, but some of it also exists in vegetable and animal bodies.

*Phosphorus* cannot be decomposed, and of course it may be considered as a simple substance.

The burning of phosphorous, of sulphur, or of carbon, is not a decomposition of those bodies, but a combination of those bodies with oxygen, which combination increases their weight, renders them miscible with water, and gives them a strong sour taste; viz. they become the *phosphoric acid*, the *sulphuric acid*, and the *carbonic acid*; so that the accession of oxygen turns them into acids; and hence the oxygen derives its name, which, from its Greek origin, means the *acidifying principle*.—The heat and the light which attend the combustion, are derived from the oxygen air which deposits them, when it loses its aërisome state, and combines with the phosphorous, or the sulphur, or the carbon.

In a similar manner oxygen combines with a variety of other substances, which combination is called *oxidation*; and the compounds, according to the different proportions of oxygen, have different properties, and different generic names, be-

sides the names of the peculiar radicals with which the oxygen is combined\*.

The combination of a very small quantity of oxygen constitutes what are called *oxides*; with more oxygen the combinations are called *weak acids*; with a quantity still greater of oxygen, the denominations are made to terminate in *ous*, viz. we say the *nitrous acid*, the *sulphurous acid*, &c. When the quantity of oxygen is as much as will completely saturate the bases, the appellations terminate in *ic*; viz. we say the *nitric acid*, the *sulphuric acid*, &c. and, lastly, when the combinations contain more oxygen than is necessary for their saturation, then those states are expressed by annexing the word *oxygennated* to the peculiar name of the acid.

All the articles, which follow *phosphorus* in the list of pages 15 and 16, as far as the zonic radical, are capable of absorbing oxygen enough to give them an acid taste, as also other properties peculiar to acids; hence they form the various acids, which derive their appellations from the names of their peculiar radicals †.

The

\* Some of those radicals (as the muriatic) are only reckoned such from analogy; for they cannot be exhibited in an uncombined state, like *sulphur* and *phosphorus*, which are the radicals of the sulphuric, and of the phosphoric acids.

† The acids are generally divided into *mineral*, *vegetable*,  
and

The articles of the list, &c. which follow the zoonic radical, and as far as gold, are called *metallic substances*:

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and *animal*, acids, according to the nature of their radicals. Acids in general have a sour taste, have a powerful affinity for alkalies, and redden certain blue vegetable colours.

The mineral acids are the sulphuric (formerly called the *vitriolic*) acid, the nitric acid, the muriatic acid (formerly called the *marine acid*), the carbonic acid (formerly called the *aërial acid*, or *fixed air*), the phosphoric acid, which is likewise an animal acid, it being found amongst animal matters, as well as among minerals, the acid of borax, the fluoric acid, the arsenic acid, the molybdic acid, the tungstenic acid, and the cromic acid. These last four are also called *metallic acids*.

Every one of the vegetable acids seems to have a compound basis, consisting of carbon and hydrogen, but in different proportions. All their radicals may be decomposed, but they cannot be compounded from simpler substances; and it is on account of this circumstance that they are reckoned amongst the primitive substances. They are distinguished from each other by their peculiar affinities for alkalies, or earths, or metallic substances. The vegetable acids are the acetic, or vinegar, the acid of tartar, the empyreumatic acid of tartar, the oxalic or acid of sorrel, the acid of galls, the citric or lemon acid, the malic or acid of apples, the benzoic, or the acid of the flowers of benjamin, the empyreumatic acid of wood, the empyreumatic acid of sugar, the acid of camphor, and the suberic or acid of cork.

The animal acids, excepting the phosphoric, likewise seem to have their bases or radicals compounded of carbon, hydrogen,

substances : they cannot combine with as much oxygen as the preceding radicals ; hence they can only form oxides, formerly called *metallic calces* ; yet from those we must except the first four, viz. arsenic, molibdenite, &c. which can combine with so much oxygen, as actually to acquire some evident acid properties. The others also have different affinities for oxygen. Those which come first in the list, have a greater affinity for oxygen than those which follow. The last four, viz. mercury, silver, platina, and gold, have less affinity for oxygen than any of the rest ; for the oxides of those metals may be deprived of the oxygen ; that is, may be *reduced* into their simple or metallic states, by heat alone ; whereas the oxides of the other metallic substances, cannot be deprived of their oxygen by heat alone, but the process must be assisted by the contact of

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hydrogen, phosphorus, and azote, in different numbers and different proportions. The animal acids are, the acid of milk, the acid of sugar of milk, the formic or acid of ants, the prussic acid, viz. the colouring matter of Prussian blue, which is obtained from dried blood, hoofs, &c. the sebacic or acid of fat, the bombic or acid of silk-worms, the lactic or the acid of waxy matter, and the zoonic, or the acid extracted from animal matter by means of lime. Those acids are also distinguished from each other by their peculiar affinities, and their bases or radicals may be decompounded but cannot be compounded from simpler substances.

some other substance, which has a greater affinity for oxygen\*.

The

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\* The metallic substances are distinguished by their absolute opacity, great specific gravity, brilliancy, and ductility ; but this last property is very imperfectly possessed by all those which precede iron in the list, and which are, on that account, called *semi-metals*. All the metallic substances become liquid in certain peculiar degrees of heat. They have different specific gravities, (see the table of Specific Gravity in page 75, and following), different colours, and different degrees of ductility ; they have also peculiar affinities for other substances. We shall briefly subjoin a few of their more remarkable characteristic properties ; commencing with the most perfect of the metals, and which has the least affinity for oxygen.

*Gold* has an orange or reddish yellow colour ; is the heaviest metallic substance, platina excepted ; it melts at about  $5237^{\circ}$  of Fahrenheit's Thermometer ; is the most perfect, ductile, tenacious, and unchangeable of all the known metals. Its proper solvents are the *nitro-muriatic acid*, (*aqua regia*), and the *oxy-muriatic acid*.

*Platina*. Its colour is white ; it is the most ponderous metal. By itself it resists the fire of ordinary furnaces, and can only be fused by means of powerful burning glasses, or in a fire urged by a current of oxygen air. It may be alloyed with most metallic substances, and in that state may be fused with much greater facility. It is not affected by the action of the atmosphere. Its proper solvents are the same as those of gold.

*Silver* has a pure white colour. It is malleable and very ductile, though not quite so much as gold. It fuses at

The seven substances which follow gold in the list, are called *earths*, or *earthy substances*; viz. *silica*,  
or

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about  $4717^{\circ}$  of Fahrenheit's Thermometer. It may be alloyed with several metals. It is dissolved by various acids, especially by the nitric.

*Mercury.* Its colour is like that of bright polished silver. It is the heaviest metallic substance next to gold and platina. It is a solid in a temperature under the  $72^{\circ}$  below freezing water. It is a liquid between that degree and  $60^{\circ}$  of Fahrenheit's Thermometer; but above that degree it becomes a vapour, or an elastic fluid. The nitric acid is its best solvent.

*Copper* has a brownish-red colour; is malleable, flexible, and ductile; though not so much as silver. It melts at  $4587^{\circ}$  of Fahrenheit's Thermometer. By exposure to the fire it changes colour, and becomes first blue, then yellow, and lastly violet. It gives a greenish-blue tinge to the flame of burning coals. It is dissoluble, more or less, in most of the acids. With the acetous acid it forms *verdigris*. Copper may be united to most metallic substances, forming various useful compounds.

*Lead* has a blueish white colour, and is the heaviest metal, after gold, platina, and mercury. It melts at  $540^{\circ}$ . Its surface is readily oxidated. It is dissolved by most acids. Its oxides form various useful colouring pigments.

*Tin* comes nearest to the colour of silver; but its surface is soon tarnished. It is very ductile, flexible, and when bent crackles in a peculiar manner. It fuses at  $410^{\circ}$ , and is pretty readily oxidated. It is dissolved more or less by most acids.

*Iron* is of a pale, somewhat bluish-grey, colour. It is the  
most

or *filex*, *argil* or *alumine*, *baryt* or *barites*, *strontian*,  
*lime*,

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most useful, most abundant, and the most diffused, metal in nature. Iron (excepting a few equivocal cases) is the only metal susceptible of magnetism. It is easily oxidated, and its colour changes according to the degree of oxygenation. It is found combined with a variety of substances, from some of which it cannot be separated without very great difficulty; hence we have iron of different qualities and of different fusibility. Cast iron melts at about  $1797^{\circ}$ . Its union with carbon forms *steel*.

*Zinc.* Its colour is between the colour of silver and that of lead. It has very little ductility. It fuses as soon as it becomes red hot, (viz. when the heat is about  $1070^{\circ}$ ) then with the access of air it inflames and sublimes in white flocks of oxide, called *philosophical wool*, or *pompholix*. It unites with several metals. With copper it forms *brass*.

*Antimony* is a whitish brilliant semi-metal, not easy of fusion, but when fused it emits a white fume called *argentine snow*, or *flowers of antimony*. The state in which this semi-metal is generally seen in commerce, and in which state it is improperly called *antimony*, is in combination with sulphur.

*Bismuth* (otherwise called *tin-glass*) is white, with a shade of red inclining to yellow. By means of the hammer it may be reduced into powder. It fuses easier than tin. When exposed to a strong heat, it burns with a blue flame, and sublimes in a yellowish smoke, which condenses and forms the *flowers of bismuth*. The nitric acid is its best solvent, Its combinations with various metallic substances, form pewter, solders, printer's types, &c.

*Cobalt* is white, inclining to bluish grey, and, when tarnished, to red. In a red heat it is malleable to a certain de-

*lime, magnesia, jargonia or zirgonia*; to which we  
shall

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gree; and, when pure, it is as difficultly fused as iron. It is not easily oxidated. When exposed to the fire in conjunction with borax, or soda, &c. and earthy substances, it tinges them blue. Its oxide, fused with sand and pot-ash, forms a blue glass, which, when finely pounded, is called *smaut*.

*Nickel*, in its pure state, has a greyish white colour. It is magnetic in a very small degree; hence it is thought to contain iron. It is malleable in a considerable degree, and is slowly oxidated in a strong heat. The nitric acid is its best solvent.

*Manganese* is of a greyish white colour, but it is so easily oxidated, as to be readily darkened by exposure to the air; it falls into powder, and becomes a perfect oxide of a dark brown or black colour. Indeed it is in that state that we always find it. This oxide, exposed to a pretty strong heat in proper vessels, yields a very great quantity of oxygen air. This metallic substance is less fusible than iron, and unites, by fusion, with every one of the metals, except mercury.

*Uranite* is of a dark steel or iron grey colour. Nitrous acid dissolves it; but its oxide is insoluble in alkalies, which circumstance distinguishes it from the oxide of tungsten, which it resembles in colour.

*Sylvanite*, or *Tellurite*, is of a dark grey colour, inclining to red. It has a considerable degree of ductility and malleability; is the most fusible metallic body, excepting mercury. It readily unites with mercury and sulphur. It is dissoluble in nitrous acid, in the sulphuric acid, and in nitro-muriatic acid.

*Titanite* is imperfectly known. Its oxide, which was formerly taken for a red *borl*, is but sparingly found united

shall add two more which have been lately discovered

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to other minerals, and from certain phenomena, which attend its dissolutions and precipitations, it appears to be the oxide of a new metallic substance, to which the name of *titanite* has been given ; but it seems that it was never fairly reduced to a metallic state.

*Chrome* has a whitish grey, shining, appearance. It is obtained from a mineral called *Siberian red lead*. It yields a particular acid, of a ruby red colour, which contains two thirds of its weight of oxygen.

*Tungsten* is supposed to be the oxide of a particular metallic substance ; for it does not appear to have ever been fairly reduced to a metallic state. It is of a steel grey colour, very hard and brittle. It affords a peculiar acid.

*Molybdenite* is a substance of a metallic lustre, which marks paper like *plumbago* (*black lead*). It is oxidated in a red heat, but it cannot be fused without a very powerful fire. Its white or red oxide gives evident marks of acid properties.

*Arsenic* is naturally white, inclining to blue ; but it speedily becomes pale yellow, and then greyish black by exposure to the atmosphere. In a metallic state arsenic is of a blackish grey colour ; it is brittle, and in its fracture resembles steel. If arsenic be placed upon burning coals, it burns with a blueish white flame, and is volatilized into a white oxide, which attaches itself to the chimney, &c. By this means arsenic is extracted from various minerals with which it is found combined. This oxide, which is fusible in water, is the *white arsenic* of commerce. This volatilized oxide has a smell resembling that of garlic, and is exceedingly dangerous to animals. Arsenic by itself fuses difficultly, but by fusion it may be united to most metals.

vered in small quantities, viz. *glucine*, and *agustine* \*.

### The

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metals. When saturated with oxygen, it constitutes an acid which may exist in a concrete form, but it readily attracts moisture from the atmosphere, and thereby becomes a fluid.

\* The earths are dry, brittle, inodorous, uninflammable, and sparingly soluble in water.

*Silica* is the earth which forms the principal ingredient of flints, rock crystal, and several gems. It is rough, and when finely pounded, a very minute quantity of it may be kept dissolved in water. The only acid which acts upon it, is the fluoric. It is infusible by itself; but in a strong heat the fixed alkalies fuse it readily, and form glass.

*Argil*, or *pure clay*, otherwise called *alumine*, (for with the sulphuric acid it forms alum) in its pure state is white, smooth, of an unctuous feel, and is diffusible in water. When heated it diminishes in bulk, is hardened, and is rendered indiffusible in water. It may be hardened so as to strike fire with steel. This most useful property enables us to form bricks, pots, and a variety of utensils, commonly known under the name of *earthen-ware*.

*Baryt*, or *Ponderous Earth*, (from its considerable specific gravity) is infusible when pure. Cold water dissolves a 25th part, and boiling water one half, of its weight. It is soluble in alcohol, and is highly poisonous. See les Annales de Chimie XXI. It has a greater affinity for muriatic acid, than any of the other earths, or the alkalies.

*Strontian*, when pure, is not fusible in the fire, but it only glitters with a phosphoric flame; it may however be fused in conjunction with most of the other earths. It is

dissolved

The last three articles of the list are called *alkalies*, they have a peculiar taste as well as other peculiar properties. Pot-ash and soda are called *fixed alkalies*, because they cannot be rendered volatile by

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dissolved readily in the nitric and muriatic acids ; and forms, by the addition of the sulphuric acid, an insoluble precipitate.

*Lime*, when pure, is called *quick lime*, or *pure calcareous earth*. Is infusible by itself, but it may be fused in conjunction with silica and argil. Lime is purified by long exposure to a strong heat, by which means it becomes white, moderately hard and brittle. It has a hot burning taste, renders violets green, and corrodes animal and vegetable substances. By the application of water it becomes hot, bursts, and becomes *slaked lime*, which, when mixed with sand, or dry mould, &c. forms the mortar commonly used for building. Slaked lime will be found to have absorbed 287 grains of water for every 1000 grains of its original weight. Water cannot hold in solution more than one 7000th part of its weight of lime, and in that state it is called *lime water*.

*Magnesia*, when pure, is white and very light. It combines with all the acids. It is infusible by itself.

*Jargonia* is a peculiar earth obtained from two gems ; viz. the *jargon* and the *hyacinth*. It is insoluble in water. In hardness and roughness it resembles silica. It is infusible by itself. It unites with the nitric, the carbonic, and the sulphuric, acids.

*Glucine* is supposed to be a peculiar earth obtained from two gems ; viz. the *beryl*, or *aqua marina*, and the *emerald*.

by means of heat ; — ammoniac is a volatile alkali \*.

But it must be observed, that the alkalies are placed in the list of simple substances, rather because they form a particular class of bodies, which are endued with remarkable and peculiar properties ; for they seem to be compounds of simpler substances. Indeed, the ammoniac has been proved to consist of 807 parts of azote, and 193 parts of hydrogen ; also the two fixed alkalies are strongly suspected of being formed from a combination of azote with some unknown bases.

The three alkalies, the acids, and the combinations, in which they enter in sufficient quantities, are called *salts*, or *saline substances* ; for a *saline substance*, in its extended chemical sense, means a substance that has some taste, and is soluble in water.

Thus we have endeavoured to give some idea of the primitive, or elementary substances ; such as

*Agustine* is supposed to be a peculiar earth obtained from a mineral that resembles the beryl. It is not soluble in water, and it becomes hard in the fire.

\* Alkalies have an acrid, urinous taste ; change the vegetable blue colours into a green ; combine with acids, and form neutral salts ; viz. salts that have neither the properties of acids, nor of alkalies. As the alkalies appear to be derived principally from azote, therefore azote has been also called the *alkaligen principle*.

may be deemed sufficient for a student of natural philosophy. A full account of their properties, affinities, combinations, &c. will be found in various recent publications written professedly on the subject of chemistry \*.

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\* See Lavoisier's Elements of Chemistry. Jacquin's Elements of Chemistry. Brisson's Physical Principles of Chemistry. Fourcroy's Chemistry. Gren's Principles of Modern Chemistry. Lagrange's Manual of a Course of Chemistry; and several other large works: to which may be added, a very useful little book; viz. Parkinson's Chemical Pocket Book, or Memoranda Chemicæ.

## CHAPTER XVII.

## OF CHEMICAL PROCESSES.

IT is perhaps scarcely suspected by most of my readers, that almost every phenomenon, which takes place about us, and which is attended with some change of property in the bodies concerned, is in fact a chemical process; viz. it does actually depend upon, and is regulated by, the laws of affinity. Heating, cooling, fires, and every sort of combustion; our respiration, our digestion, the formation, decomposition, and secretion, of the various animal fluids; evaporation, dissolutions, and fermentations; the operations carried on in the various arts of dyeing, bleaching, tanning, &c. are all depending on the various affinities of bodies. Infinite is the number and the variety of the particular processes; and even the account of a select number of them, is what fills up many large and learned works. In these elements we can only attempt to describe the most remarkable of those processes; viz. such as are more general or more interesting, and which may not only elucidate the general theory of chemistry, but may also assist the

the reader in the investigation of other phenomena\*.

*Combustion*, in its modern enlarged sense, means every operation in which oxygen air is decomposed, its radical; viz. the oxygen, is absorbed, and its other two components, caloric and light, are set at liberty, or enter into other combinations. Therefore respiration, the oxydation of metallic bodies, and, in short, the oxidation of all other substances, are different degrees of combustion. Those bodies, which have so much affinity for oxygen, as to be able to decompose oxygen air, are called *combustible bodies*.

When the oxygen air is decomposed slowly, the heat is imperceptible, because the caloric is dissipated as soon as generated. When the decomposition goes on faster, the bodies concerned become sensibly warm. A quicker decomposition of the oxygen air heats the bodies so as to render them red hot; (this temperature is equal to about 100° of Fahrenheit's Thermometer) which state is called *ignition*. When the process is attended with the production of certain fluids, as hydrogen, volatile

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\* Whoever wishes to examine this subject at large, may peruse some of the valuable works which are mentioned in the note at the end of the preceding chapter; as also a variety of works written expressively on the arts of dyeing,

oils, &c. and the decomposition of oxygen air affords a sufficient developement of caloric; then the above-mentioned fluids themselves are ignited and decomposed, which constitutes the *flame*, and is thence called *inflammation*. The quickest decomposition of oxygen air is attended with a very quick extrication of caloric, a sudden expansion of the contiguous bodies, and of course with a sudden noise; hence it is called *detonation*. A quick succession of little detonations, is called *decomposition*, or *deflagration*.

Combustions are generally attended with the decomposition and formation of several compounds; viz. the carbon, which naturally exists in vegetable and animal substances, unites with part of the oxygen, and forms *carbonic acid gas*; some of the neutral salts are decomposed, and an alkali is left intermixed with what fixed matter remains after the combustion, &c.

Two principal facts must be particularly remarked in this place. First, that the greatest part of the heat, which is yielded in combustion, comes from the decomposition of the oxygen air; and secondly, that the oxygen air is the general, and the only substance, which by its decomposition, &c. can produce combustion. In fact, where no oxygen air exists, as in vacuo, in azotic gas, in hydrogen gas, &c. there combustion cannot take place; an animal cannot respire, a metallic body cannot be oxidated,

oxidated, or in general a combustible body cannot burn ; for instance, a piece of charcoal, exposed to a strong fire in a close vessel, will not thereby be altered.

The atmospherical air is useful for those purposes, so far as it contains oxygen air. When that portion of oxygen, which is about a quarter of the atmospherical fluid, has been more or less, or entirely, separated, the remainder will accordingly be found less fit, or quite unfit for respiration, for combustion, &c. Hence will appear the necessity of ventilating towns, houses, ships, &c.

If you place a lighted wax taper under a glass receiver, which is inverted with its aperture in water, and is situated upon the shelf of the tub, fig. 8. Plate XVII. you will find that as the flame decomposes the oxygen air, and of course less and less of that air remains within the receiver, so the flame becomes gradually smaller, less active, and at last ceases to burn. After the cooling of the apparatus, you will find the water to have risen within the receiver, and to occupy the place of the decomposed oxygen air ; viz. about one quarter of the original bulk of the common air. The remaining azotic gas is unfit for combustion. This gas contains a small quantity of carbonic acid gas, which has been formed by the union of the carbon of the wax with some of the oxygen. This carbonic acid gas may be separated from the azotic gas by

agitation in lime water, which absorbs it, and leaves the azotic gas by itself\*.

If the glass receiver be filled with pure oxygen air, the wax taper will be found to burn for a longer time, with a much more active and luminous flame; and the air will disappear almost entirely, excepting only the carbonic acid gas which has been formed, and a small portion of oxygen air which remains mixed with the acid gas.

The most active fire which we can possibly produce, is obtained by passing a current of oxygen air, instead of common air, through burning coals, or other combustibles.

For the support of animal life, a constant supply of heat is indispensably necessary, and the caloric, which produces that heat, is derived from the decomposition of oxygen air in the course of respiration. A certain quantity of carbonated hydrogen gas is supposed to be disengaged from the blood in the lungs ; the oxygen of the air, which is inspired,

\* Gun powder may be fired in *vacuo*, and compositions of gun-powder, nitre, &c. may be made to burn under water ; but in those cases the oxygen, necessary for the combustion, is afforded by the nitre, or by some other salt analogous to it. In fact, if nitre be put by itself in an earthenware retort, and the retort be exposed to a fire sufficient to render it strongly red hot, or rather white hot, the nitre will yield abundance of oxygen air, which may be received in a receiver full of, and inverted in, water.

combines

combines with the hydrogen, and with the carbon of the above-mentioned gas, and parts with its caloric; thus carbonic acid gas and water is produced, (for, as it will be shewn in the sequel, water consists of oxygen and hydrogen). The caloric which is disengaged in this process, expands itself through the adjoining parts, and supplies the heat necessary for animal life.

If the atmospherical fluid consisted entirely of oxygen air, then a much greater quantity of heat would be produced by respiration than is necessary for the support of animal life, the combustion of bodies would likewise proceed too rapidly, and of course decompositions of every sort would go on with useless precipitation; hence we may thankfully admire the just and temperate constitution of the atmospherical air.

One of the most remarkable discoveries of modern times, is the decomposition and composition of water, which was formerly considered as an elementary or simple substance. This decomposition has been effected two ways principally ; viz. by placing the vapour of water in contact with certain ignited bodies, or by means of electricity. The most satisfactory methods of decomposing, and of composing it, are clearly described by M. Brisson, in the following words :

i. " A tube of common glass, E F, fig. 11.  
Plate XVII. well annealed, and difficult to be fused,

" The gases disengaged were found to weigh altogether 113,7 grains.

" There were found two different kinds of gas; viz. 144 cubic inches of carbonic acid gas, weighing 100 grains, and 380 cubic inches of a very light gas, weighing 13,7 grains. This last gas took fire on being applied to a lighted body in contact with the air.

" In examining afterwards the weight of the water which had passed into the flask, it was found less than that in the retort A, by 85,7 grains. In this experiment, therefore, 85,7 grains of water, and 28 grains of charcoal, formed carbonic acid gas, equal to 100 grains, and a peculiar gas susceptible of inflammation, equal to 13,7 grains.

" We have already said, that to form 100 grains of carbonic acid gas, 72 grains of oxygen must be united to 28 grains of charcoal or carbon. The 28 grains of charcoal put into the glass tube EF, took, therefore, from the water, 72 grains of oxygen, since there was formed carbonic acid equal to 100 grains.

" It appears therefore that 85,7 grains of water are composed of 72 grains of oxygen, and 13,7 grains of a substance, forming the base of a gas susceptible of inflammation.

.3. "The apparatus being arranged as above, instead of the 28 grains of charcoal, 274 grains of thin shavings of iron, rolled up in a spiral form, were introduced into the tube EF: the tube was then brought to a red heat

as before ; and in the like manner the whole of the water in the retort A, was made to evaporate.

" In this experiment there was disengaged only one kind of gas which was inflammable : there was obtained of it about 406 cubic inches, weighing 15 grains. The 274 grains of iron, put into the tube E F, were found to weigh above what they did when introduced, 85 grains, and the water first employed was diminished 100 grains.

" The volume of these iron shavings was found to be greatly enlarged. The iron was scarcely any longer susceptible of attraction by the magnet ; it dissolved without effervescence in acids : in a word, it was in the state of a black oxide, like that which has been burnt in oxygen air.

" In this experiment there was a real oxidation of the iron by the water, entirely similar to that effected in the air by the aid of heat ; 100 grains of water were decomposed, and of these 100 grains, 85 united to the iron, to reduce it to the state of black oxide : these 85 grains, therefore, were oxygen ; the remaining 15 grains combined with caloric, and formed an inflammable gas. It hence follows, that water is composed of oxygen, and the base of inflammable gas, in the proportion of 85 to 15, or of 17 to 3.

" Water, therefore, besides oxygen, which is one of its principles, and which is common to it with a great many other substances, contains another peculiar to itself, and which is its constituent radical.

...  
pable of containing about 30 pints, and  
to its mouth a small plate of copper B C,  
above it a cylinder of the same metal, g D,  
with three holes to receive three tubes. T  
of these, b H, is destined to be connected, at  
tremity b, with an air-pump, in order that  
balloon A, may be exhausted of air. The  
tube gg, communicates by its extremity g  
with a reservoir of oxygen gas, and is de-  
signed to convey it into the balloon A. The third tube  
communicates by the extremity N N, with a re-  
servoir of hydrogen gas: the extremity z of this  
terminates in an aperture so small as scarcely  
admit a very delicate needle. It is through  
aperture that the hydrogen gas, contained in the  
reservoir, is to pass into the balloon A. In its  
place, the small plate BC is pierced with a  
hole, into which is inserted with cement, a  
tube, through which passes a wire F L, having  
its extremity L, a small ball destined to

" That the gases may be conveyed in a very dry state through the tubes which conduct them into the balloon A, and that they may be deprived of water as much as possible, you must put into the swelled parts, M M, and N N, of the tubes, some salt capable of attracting the moisture with great activity. These salts should be only coarsely pounded, in order that they may not form a mass, and that the gases may pass freely through the interstices left between the fragments. You must be provided with a sufficient quantity of very pure oxygen gas, and nearly a triple volume of hydrogen gas, equally pure. To obtain it in this state, and free from all mixture, you must extract it from water, decomposed by means of very pure and ductile iron.

" When every thing has been thus prepared, adapt to the air-pump the tube b H, and exhaust the air in the large balloon A; then fill it with oxygen gas, by means of the tube g g, and, by a certain degree of pressure, force the hydrogen gas to pass into the balloon A, through the extremity of the tube z D d; then kindle this gas by means of an electric spark; and if you renew the quantity of each of these two gases, the combustion may be continued for a long time.

" In proportion as the combustion proceeds, water is deposited on the internal surface of the balloon A: the quantity of this water gradually increases, and it unites into large drops, which

run down the sides of the vessel, and are collected at the bottom of it.

"The sum of the weights of the gases employed, and the weight of the water formed, were found to be equal, within a 200th part. It was by an experiment of the same kind, that Lavoisier ascertained, that 85 parts, by weight, of oxygen, and 15 parts, also by weight, of hydrogen, are required to compose an hundred parts of water.

"These phenomena of the decomposition, and recombination of water, are continually effected before our eyes, by the temperature of the atmosphere, and the agency of compound affinities. It is this decomposition which gives rise, at least in a certain degree, to the phenomena of spirituous fermentation, those of putrefaction, and those even of vegetation."

The dissolution of metallic substances in acids is a very important and remarkable operation of chemistry. When a metal is placed in a fluid acid, capable of dissolving it, heat and effervescence (viz. a disengagement of gas) frequently takes place, and the gas is either the nitrous, or the sulphurous acid, &c. according to the nature of the acid ; the metal gradually diminishes in bulk, and at last none of it is to be seen. The liquor thus loaded with the metallic substance, is called the *solution of the metal*. If an alkali, or certain other substances, be added to the solution, the metallic substance will be separated

separated from the fluid, and will fall to the bottom of the vessel. This is called the *precipitate*, and the alkali or other substance that has been added to the solution, is called the *precipitant*. The precipitate, in certain cases, appears in a metallic state, viz. a powder, or crust of the original metal; but it generally appears in the form of a salt; viz. quite destitute of the metallic appearance: it is, in short, an oxyde of the metal, which may be reduced to a metallic state by depriving it of the oxygen. This last process is called *reduction*.

Such are the general phenomena of metallic dissolutions, and the operations of affinity seem to be simple and evident; but a closer examination of particular dissolutions, and of the facts which attend each of them, shew that the subject is much more intricate than it may at first sight appear. In short, it is manifested by a variety of experiments, that water is absolutely necessary for every dissolution; that the water is decomposed as well as the metal and the acid, and that new compounds are thereby formed. Nearly the same thing may be said of reductions; but the number of ingredients of decompositions and compositions, which act and are produced in every particular case, are in part known, and in part guessed at. Several elegant experiments in elucidation of this subject, which shew the above-mentioned necessary presence of water, and a variety of collateral particulars, were

furnished to the scientific world by an ingenious female writer \*.

Some idea of the primitive substances has been given in the preceding chapter; but by far the greater number, if not all, the bodies which naturally occur to our senses, are compounds of several of the primitive substances; and their ingredients are in great measure to be ascertained by trials, and by employing other simpler and determinate substances.

Each of the three kingdoms of nature are divided by the chemists into subordinate divisions. The mineral is divided into earthy, metallic, saline, and bituminous, minerals; of which a general idea has been given in the preceding pages, excepting the bituminous; but these seem to have a double origin; viz. they seem to partake of the mineral and of the vegetable kingdom; for they are found to contain several of those ingredients which belong principally to vegetables, and perhaps to animals too.

Vegetables seem to derive their nourishment

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\* See Mrs. Fulhame's Essay on Combustion, &c. London 1794. See also a short account of Dr. Woodhouse's Experiments in the Philosophical Magazine, vol. VII. p. 83. and the Chemical Works mentioned at the end of the preceding chapter, in which the particular phenomena that attend a variety of dissolutions and reductions will be found.

chiefly from water, which is decomposed by the powers of vegetation, and its components enter into new combinations. The hydrogen becomes an essential principle of plants, and enters into the formation of their resins, oils, and mucilage. Part of the oxygen forms the acid juices of vegetables, and another part is expelled, when the plants are exposed to a strong light, in the form of oxygen air; but when the plants are in the dark, as at night, then they give out principally the carbonic acid gas. The common air which surrounds a plant contributes to its vegetation, by affording it oxygen in certain cases, as also by depositing moisture upon, or taking it away from, its surface, according to circumstances. Nitrogen is likewise absorbed by plants.

Light, caloric, and carbon, do also seem to enter into combination with vegetables, and to be necessary for their growth.

Most of those principles may be extracted, by decomposition, from all plants; but, besides those, there are several others which may be extracted from particular plants.

Though we find that most plants are resolvable into the above-mentioned principles; yet it must be acknowledged that the chemical art cannot imitate, or form, any vegetable, no more than it can form any animal, part. The real proportion of the ingredients, the manner of combining them,

and probably the necessary concurrence of other elements, are far from being ascertained.

By the decomposition of plants (I do not mean an extreme decomposition) several useful substances are obtained; the most remarkable of which we shall briefly enumerate.

The *sap* is the general, or more abundant, fluid of a plant, from which the various peculiar juices, resins, oils, &c. of the plant, are secreted, by the organism of the plant and the powers of vegetation.

The *mucilage*, which forms the basis of most vegetable productions, has the following peculiar properties. It is insipid; is soluble in water, but not in alcohol; is coagulable by the action of weak acids, and of metallic solutions.

*Gum*. is a consistent substance, soluble in water. It is found concreted in certain places on the surface of plants, and is supposed to be only inspissated mucilage.

Oils are distinguished into *fixed* or *fat oils*; viz. such as contain mucilage, and cannot be rendered volatile without a considerable degree of heat; and into *volatile oils*, which contain *aroma*, or the odoriferous part of the plant. By distillation oils yield a phlegm, an acid, a fluid, or light oil, a considerable quantity of hydro-carbonate gas, carbonic acid gas, and leave in the retort:

residuum

residuum which does not afford any alkali, as the ashes of most vegetables do. The volatile oils afford a greater proportion of hydrogen gas, and the fixed oils a greater proportion of carbonic acid gas ; for this gas is in great measure derived from the mucilage.

- *Resins* seem to be oils concreted by the combination with oxygen. They are inflammable, soluble in alcohol, and in oils, but not in water.

*Gum resins* seem to be mixtures of mucilage and of resins ; for they are partly soluble in water, and partly in alcohol.

*Fæcula* seems to be little different from mucilage. The principal circumstance, in which they seem to differ, is, that fæcula is not soluble in cold water.

*Vegetable gluten*, is an adhesive substance, obtained principally from the flour of farinaceous plants, by forming a paste of that flour, and kneading it in water, until it no longer tinges the water.

*Sugar* is an essential salt, which may be extracted in various quantities from different plants.

*Albuminous Matter of Vegetables*, is a flocculent matter, which is extracted from the juice of certain plants, and in some measure resembles the white of an egg, whence it has derived its name.

The different acids, which may be obtained

from vegetables, have already been enumerated in the preceding chapter.

The constituent principles of plants have different affinities; but the proportion of those principles in a living plant, is such as to balance their peculiar affinities; and the excess or defect of each principle is easily expelled or absorbed by the action of vegetation. But when vegetation ceases, then the action of the atmosphere, which heats or cools, or oxygenates, or dries up, or moistens, the vegetable substances, soon disturbs that just proportion of ingredients, and produces a variety of effects. If the vegetable abound only in moisture, a dry air and ventilation will dry it up; and such is the case with wood, seeds, &c. When the vegetables are very juicy, and those juices contain a variety of principles, then those principles begin to separate, the heaviest go to the bottom, the most volatile fly away, an intestine motion is thereby produced, new combinations take place, &c. This decomposition in general is called *fermentation*. In different states of it different effects are produced, and from those effects it derives three different names; viz. of *vinous*, *acid*, and *putrid*, *fermentation*.

The *Vinous Fermentation*, or *Spiritous Fermentation*. In order to produce this fermentation, the expressed juice of grapes (and the same thing with little difference may be said of the juices of several other fruits) is placed in an open vessel, or vat, and

and is kept gently warm, as about  $70^{\circ}$  of Fahrenheit's Thermometer. The liquor soon grows turbid, and an intestine motion takes place through the whole mass, attended with a copious discharge of carbonic acid gas, and a frothy substance called *yeast*. After a day or two, and sometimes longer, the phenomena gradually diminish, and cease almost entirely. In that state the liquor is pretty clear, and will be found to have acquired a vinous taste and odour; and the thickest or more consistent part will be found settled at the bottom of the vessel. Now if the progress of dissolution be stopped, which is done by separating the clear liquor from the thick sediment, by preventing the access of air to it, by placing it in a cooler situation, &c. then the liquor remains with little alteration in the state of *wine*. But if the whole be left undisturbed, the fermentation will pass on to the next stage; viz. to

*The acetous Fermentation.* This consists in the absorption of oxygen from the atmosphere; and the result is *vinegar*, or the *acetous acid*.

*In the putrid Fermentation* the colour of the vegetables changes; they grow pretty hot, and a mixture of gaseous is disengaged; viz. of azote, hydrogen, carbonic acid, and ammoniacal, gases. This process completes the dissolution of the vegetable substances.

Wine, or fermented liquors, yield, by distillation, an inflammable and odoriferous liquor,

called *spirit of wine*, and, in its purest state, *alcohol*.

Alcohol seems to be formed from an intimate combination of hydrogen and carbon, and is perfectly miscible with water.

Alcohol mixed with the sulphuric, or the nitric, or other acid, and then distilled, yields the lightest liquid known. This liquid is called *ether*, to which the name of the acid is added ; viz. it is called the *sulphuric*, or the *nitric*, or the *muriatic*, or the *acetic ether*, according to the nature of the acid which has been employed for its production.

Ether seems to be formed from a combination of the oxygen of the acid, with the carbon and the hydrogen of the alcohol. It has a peculiar smell, is very volatile, and highly inflammable. If ether be mixed with an equal bulk of water, about a quarter of it will be dissolved by the water ; the other three quarters, which are purer than previous to the mixture, will be found to swim upon the water.

Animal substances, whether solid or fluid, consist of, for they are resolvable into, the following principles ; viz. *azote*, *carbon*, *hydrogen*, *oxygen*, *phosphorus*, and *lime*. The various, but unknown, proportions, the number, and the arrangement of those ingredients, constitute the blood, the milk, the gall, the bones, the muscles, the fat, and all the other parts of animal bodies. But with respect to the facts which have been ascertained, or the conjectures

conjectures which have been offered, relative to the original formation, growth, secretion, form, situation, and other properties of those animal parts, I must unavoidably refer the reader to the works of the anatomical and chemical writers: we shall, however, subjoin a short account of the natural process of the putrefaction of animal substances, with which we shall close the present volume.

An animal, like a vegetable, when deprived of life, begins to undergo a decomposition or separation of its constituent principles; and this decomposition is assisted and promoted by a moderate warmth, by moisture, and by the access of air. It must be observed, however, that animal dissolution does not go through the vinous and acetic states of fermentation; but it proceeds directly to the putrid, principally on account of its containing more azote and much ammonia; excepting a few animal fluids, which, by proper treatment, may be caused to undergo a vinous or acid fermentation.

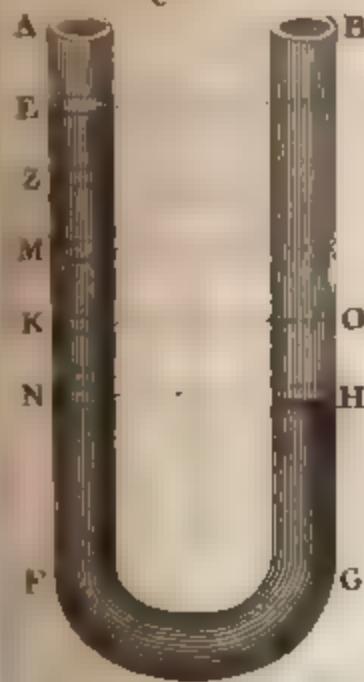
The colour and the consistence of dead animals first begin to diminish, and an unpleasant odour is exhaled. The colour, after having become pale, changes to blue and green, then to dark brown, according as the parts become less consistent, and the putrid effluvium becomes more penetrating, nauseous, and injurious. This production of gases gradually increases in pungency and variety; and, from the separation of phosphorous, it is often attended with a phosphorescent light. The mass of

matter, already become very soft, swells, and, lastly, produces carbonic acid gas. When all the most volatile parts have been disengaged, the fixed radicals, containing some hydrogen, form a brown, soft, earthy matter, which, if left exposed to the atmosphere, becomes, in process of time, a powdery pale substance; but if mixed with mould, forms *soil* fit for vegetation.

The putrid process of animal substances may be checked or prevented by various means, such as placing the substances in cold situations, freezing, drying up the moisture which is necessary for fermentation, introducing resinous substances, placing the substances in spirit of wine, &c.

THE END OF VOL. II.

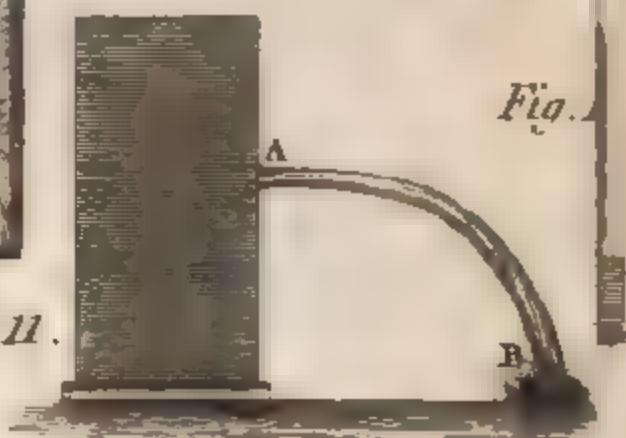
*Fig. 1.*



*Fig. 10*

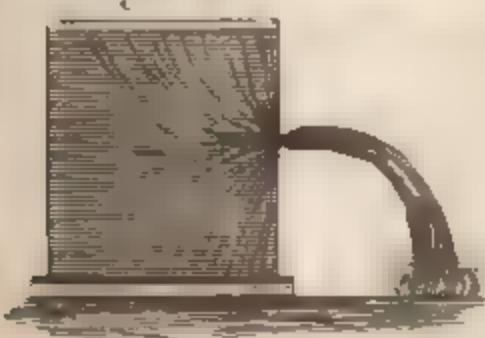


*Fig. 11.*



*Fig.*

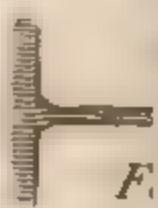
*Fig. 14.*



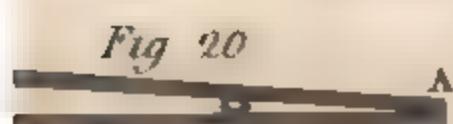
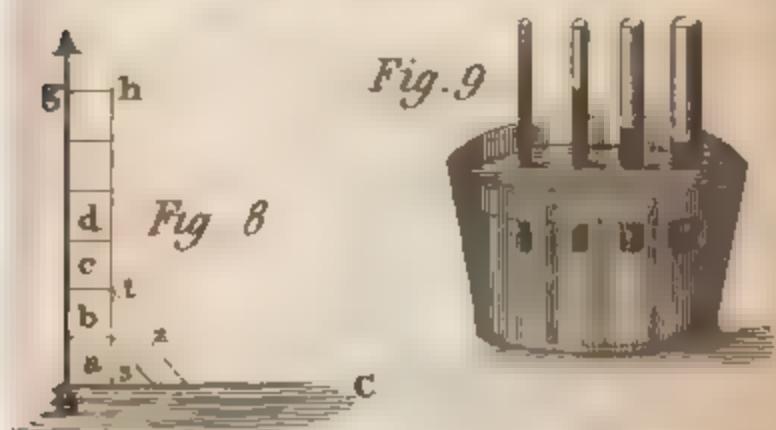
*Fig. 12.*



*Fig. 15. Fig.*



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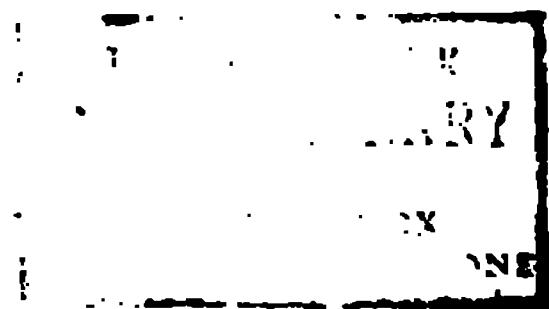


Fig.

Fig. 8.

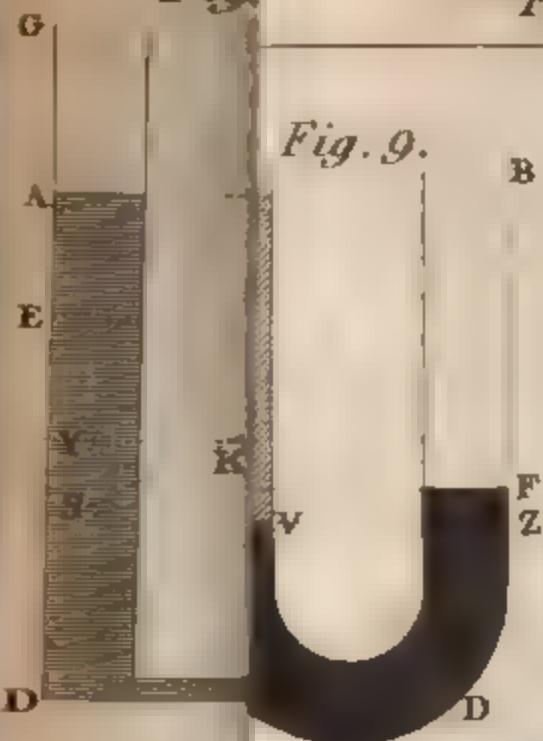


Fig. 9.

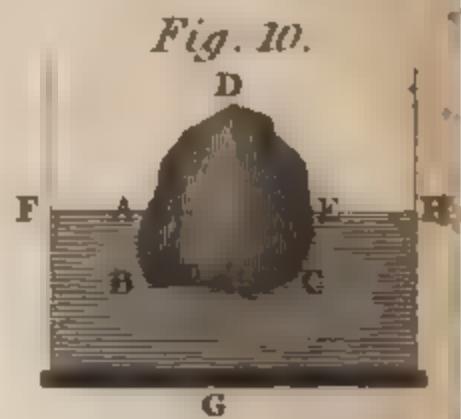


Fig. 15.

Fig. 16.



Fig. 1.

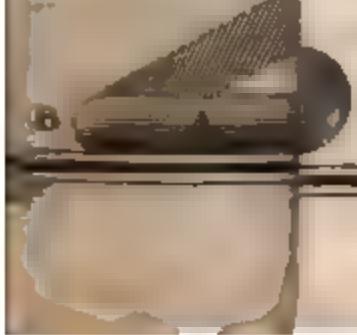


Fig. 19.

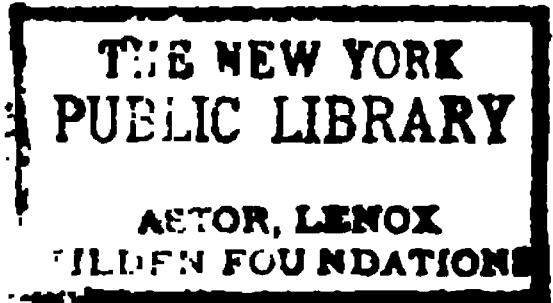


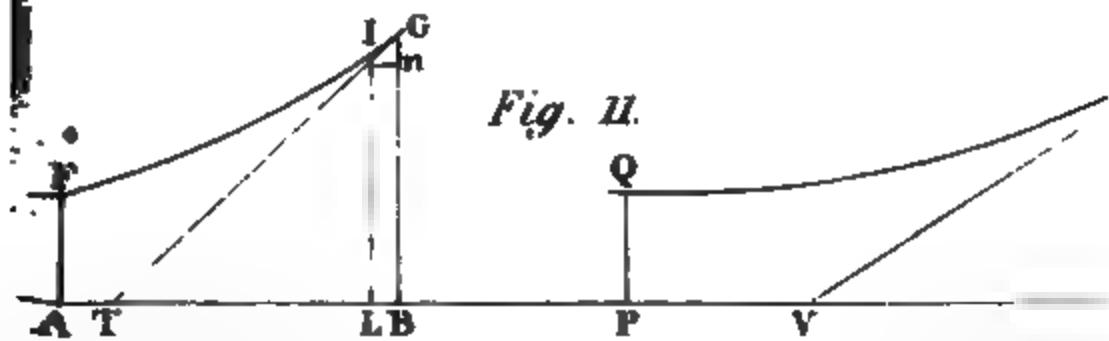
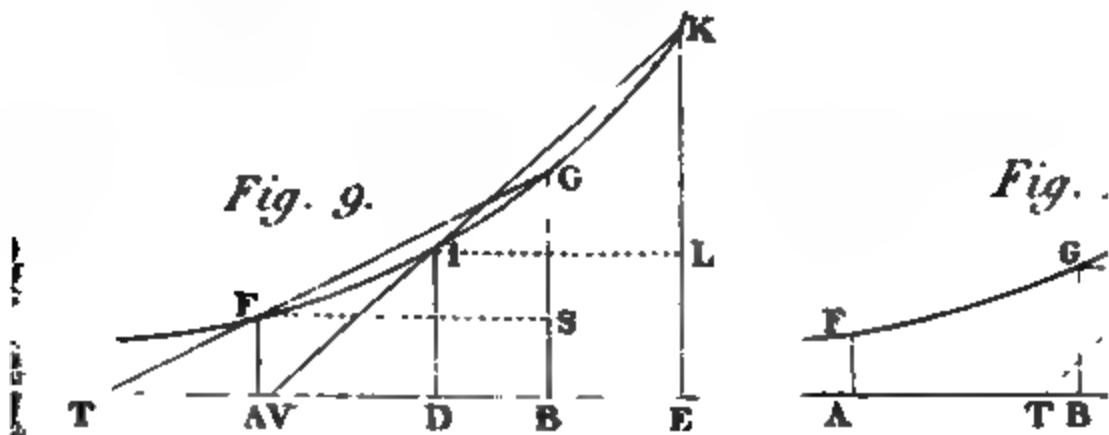
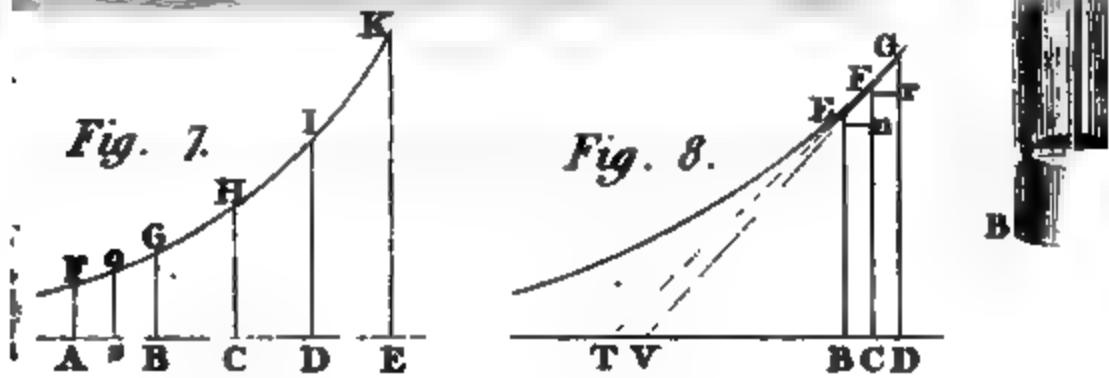
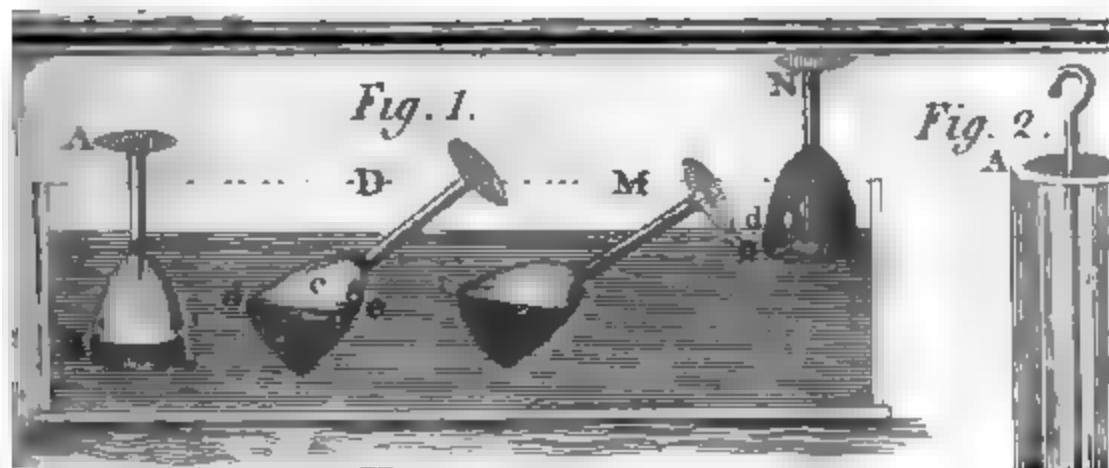
Fig. 20.



Fig. 21.









Finley  
Frederick

Foster

Garrison

Hall  
Lyman

Sophia

Banta

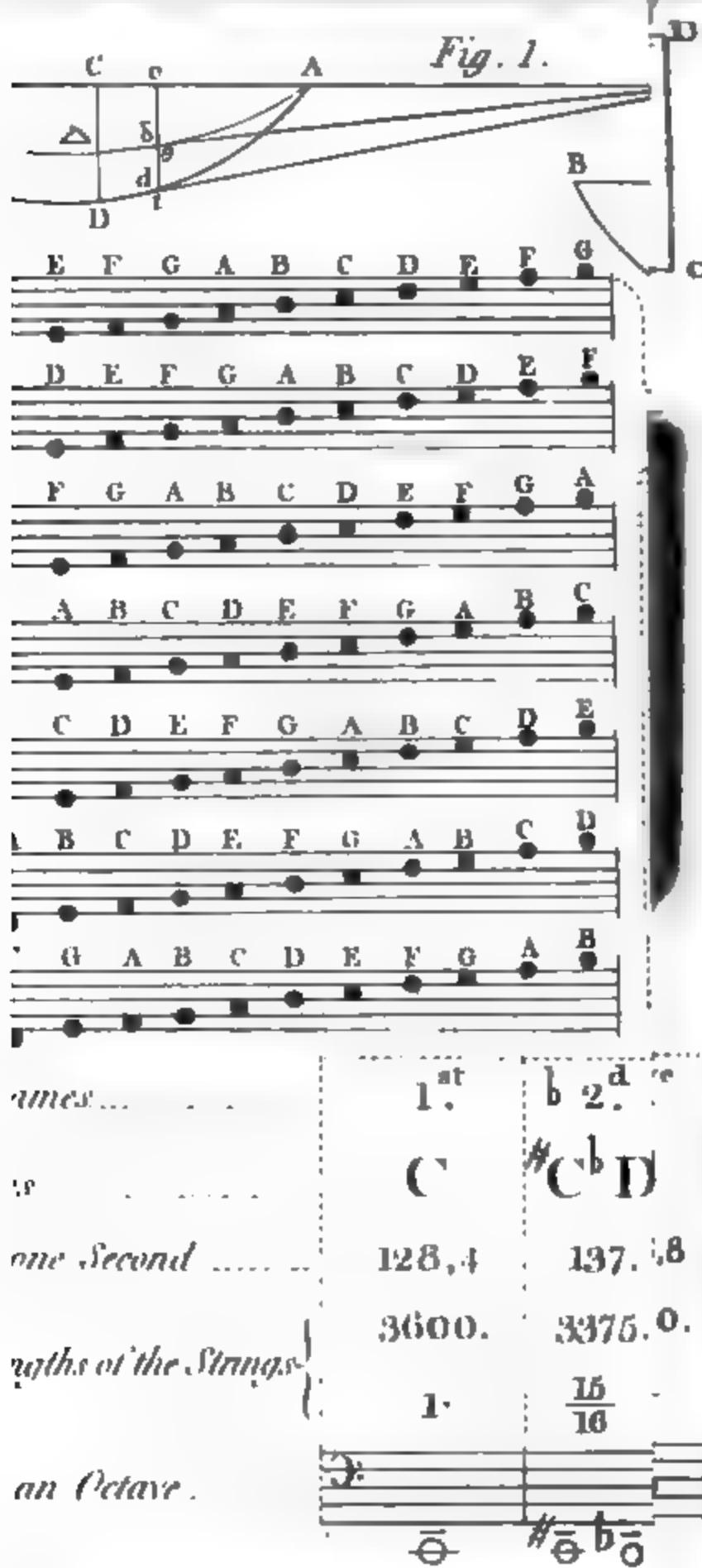
Bais

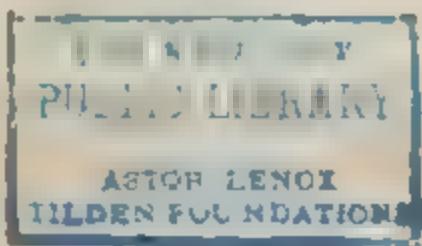
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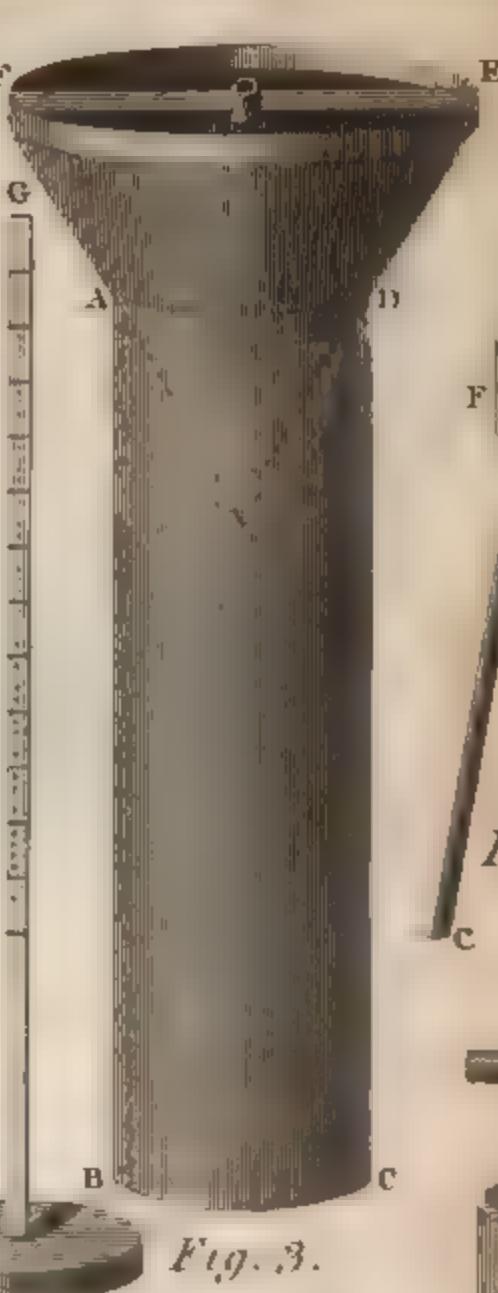
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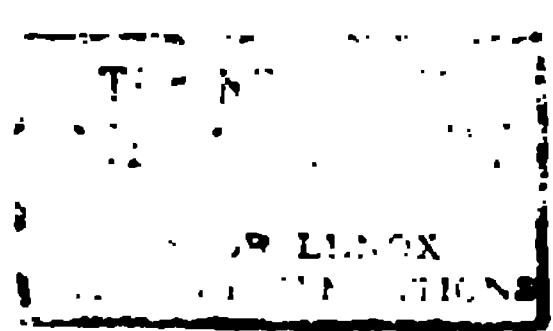
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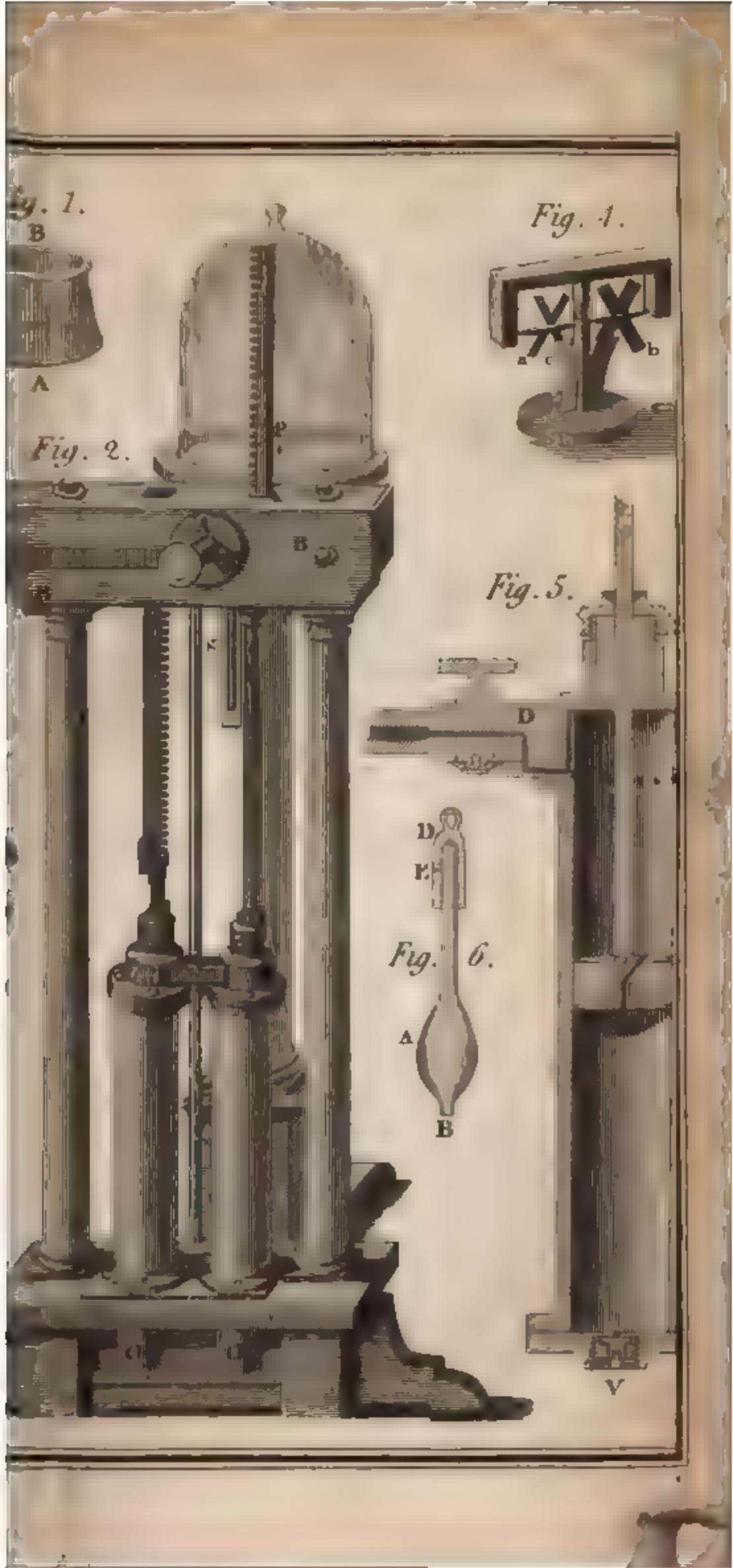
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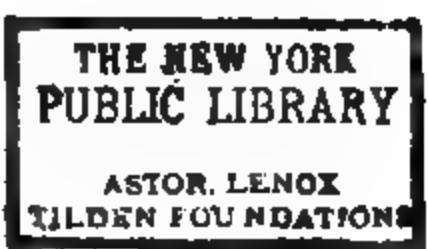




*Fig. 2.**Fig. 3.**Fig. 4.**Fig. 14.**Fig. 10.**Fig. 15.*







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